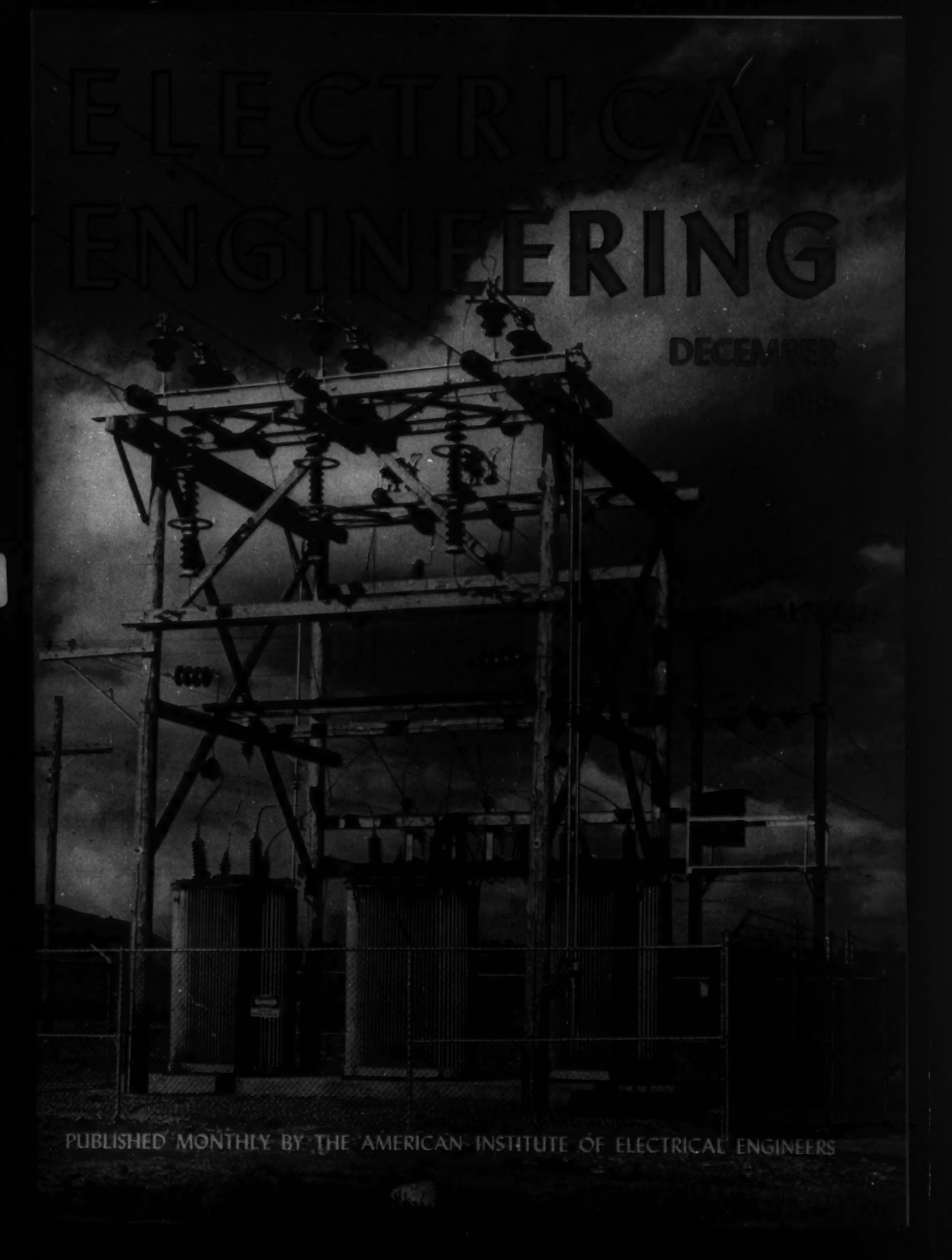
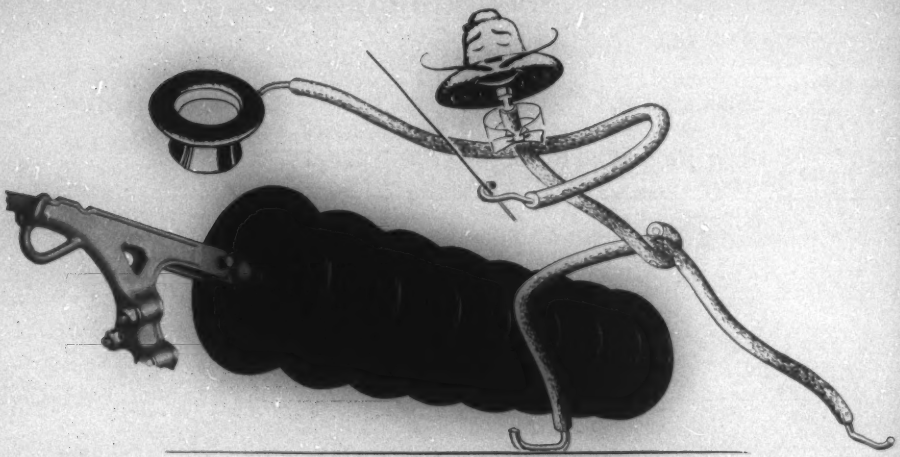

ELECTRICAL
ENGINEERING
DECEMBER
PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS



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Let's not over-emphasize the matter of brute strength in suspension insulators. It's no great accomplishment to build a strong insulator, or everybody wouldn't be doing it...The really important side of the strength story is the ability to build insulators to a definite strength standard, and then not miss that standard in any number of times...There was a time when strong insulators and those not so strong were averaged together to produce a strength rating that concealed the weakest units. This worked in all but a very few cases. These few, however, were potential trouble-makers simply because they deviated too far from a standard...O-B was the first to correct this. It took years of painstaking development to institute factory practices and inspection procedures which made it possible to brand all insulators with a minimum strength value--a rating below which no O-B unit will go...Look at any O-B suspension unit today and you will find permanently cast into the cap a strength figure which *really* means something because it is a guaranteed minimum, *not an average*...Use O-B insulators and get the kind of strength that counts, because you can count on it!

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December 1943, Vol. 62, No. 12. Number of copies of this issue 34,900

YOU CAN BREAK LOAD WITH THIS SWITCH

Wall Mounting Type

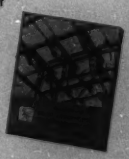
and Get Short-Circuit Protection with a Fuse Combination

● Manual switching of high voltage circuits—and reliable short-circuit protection are provided in one unit assembly,—in one cabinet, by the Load-Interrupter Disconnect and Fuse Equipment designed and pioneered by S&C.

The Load-Interrupter Switch is capable of interrupting up to 400 amperes at 15,000 volts without drawing an arc across the main switch contacts. The Heavy Duty Fuses have short-circuit interrupting ratings of:—20,000 r. m. s. amperes at 13,200 volts; 25,000 r. m. s. amperes at 6600 volts; 30,000 r. m. s. amperes at 2300/4000 volts.

For many services where all the functions of circuit-breakers are not essential, this load-switching and fuse combination assembly has found wide acceptance during the past few years, effecting savings in initial installation and maintenance costs, and conserving critical metals.

These assemblies are installed at substations, main and branch feeders, and employed as throw-over devices from two alternate feeders. Consult the nearest S&C office for further details of this equipment and its many applications,—or write today for Bulletins 202-A and 763.



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4435 Ravenswood Avenue CHICAGO, ILLINOIS

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...yet still in action

For years, Manson Tape has occupied the highest position of all friction tapes. Whenever the utmost safety and permanence in splice protection was required, Manson Tape became the first choice of experienced engineers and electricians. Purchasing agents, too, willingly paid more to get lasting protection.

Contributing to this fine reputation of Manson Tape was the pledge of The Okonite Company to use only the best materials in its manufacture. One of these materials was a special type of natural rubber, which thoroughly impregnated and coated the strong, closely-woven cotton fabric. The exclusive use of this special type of new rubber was one reason why Manson Tape was unequaled in true adhesiveness and in aging and weathering qualities.

Today, with *all* new rubber forbidden for this use, the manufacture of Manson Tape has been temporarily discontinued because, if made with the materials currently available, Manson Tape would not have the superior characteristics nor be of the same high quality that you have always known.

As an assurance to the thousands of electrical men who have so consistently used it, we remind them that older joints and terminals made with Manson Tape will stay protected for years to come. To those who are fortunate enough to have available a supply of Manson Tape, we suggest it be reserved for the most important jobs.

UNTIL MANSON TAPE IS AGAIN AVAILABLE

We recommend as an alternative, *Dundee "A" Friction Tape* which fully complies with all current Federal and A.S.T.M. emergency specifications.

THE OKONITE COMPANY

PASSAIC OKONITE NEW JERSEY

3436

MANUFACTURERS OF INSULATED WIRES, CABLES AND TAPES SINCE 1878

Micromax Recorder at left shows temperature of 6 points in stator, and also of exciter air and outlet water of the hydrogen cooler of a generator in Ohio. Recorder at right shows temperature of the field. Watching these 9 temperatures is essential when carrying heavy load, though Recorders will also sound alarms if any one temperature exceeds a predetermined point.

OVERLOAD PILING UP?

Fields and Stators Are Safer When A Micromax Recorder Watches Each

Loading of electrical generators on the basis of the temperatures of their stators and rotors is a practice which is now gaining ground, especially where load is so heavy that individual machines must carry even more than their usual percentage of nameplate-rated loads. Many power companies are now running special tests to determine the amounts of load which may be added, under specific conditions, to that given as maximum on the nameplate. Here are some of the factors to be considered:*

1. Each generator is a separate problem.
2. Nameplate data may provide unnecessarily large safety factor for load swings, unbalanced phases, etc.
3. Ambient temperature may be less than nameplate specifies.
4. Power factor may be higher than specified.
5. Change in terminal voltage may permit greater output.
6. When starting from low temperature, a generator can carry short-time excess load because of its own temperature lag.
7. In emergencies and for short peaks it may be more economical to operate at extraordinary temperature and thus age the insulation at an abnormal rate, rather than to provide the additional rated capacity for short-time loads.

When a generator is loaded on the basis of temperature, we can supply its operator with complete temperature readings by means of two instruments—a Micromax Stator Temperature Recorder and its companion, a Rotor Recorder.

The Stator Recorder shows the temperature of 6 points, and of incoming and outgoing cooling medium. It sounds an alarm if a peak temperature is reached.

The Rotor-Temperature Recorder measures the resistance of the entire field and records it as temperature. Devised about 15 years ago, it has been less used than the Stator Recorder, for the reason that not every generator normally needs both instruments. As load becomes abnormal, or unfavorable power factor conditions occur, however, it is often wise to measure the field temperature directly.

Further information in Catalog N-33-161.

* Abstracted from a small portion of AIEE Miscellaneous Paper 43-93, "Interim Report on Emergency Measures to Increase Output of Generating Equipment and Systems", June 1943, available at 65¢ from AIEE, 33 W. 39th St., New York City.

NEW! SPLIT-CHART MICROMAX FOR STEAM TEMPERATURES

When you want clearly to separate two temperatures recorded by one instrument, and they are almost identical, you can keep them from recording on top of each other by using a Split-Chart Micromax Recorder. shown above. All temperatures of one boiler go on left-hand; all of other boiler go on right-hand; thus there's no confusion. Designed especially for power-plants. with daily tear-off and multicolor record if desired. Further facts either from an L&N Engineer or from Folder N-163(2) as you prefer.

Jrl Ad N-33-161(4)

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He started in Electronics on the ground floor . . . with *radio*. His advice and recommendations about circuits, tubes, and other electronic components are valuable to you.

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He's right around the corner; check with him first for items you need to fill on a rush priority basis.

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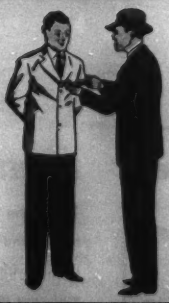
If his normally adequate and varied stock should *not* include what you want, he's your one best bet today for locating it *fast!*



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He's an old hand at tackling tough jobs. That's his business.
When you're in a jam, you'll find him well qualified to act as your expediting specialist.

BUY WAR BONDS

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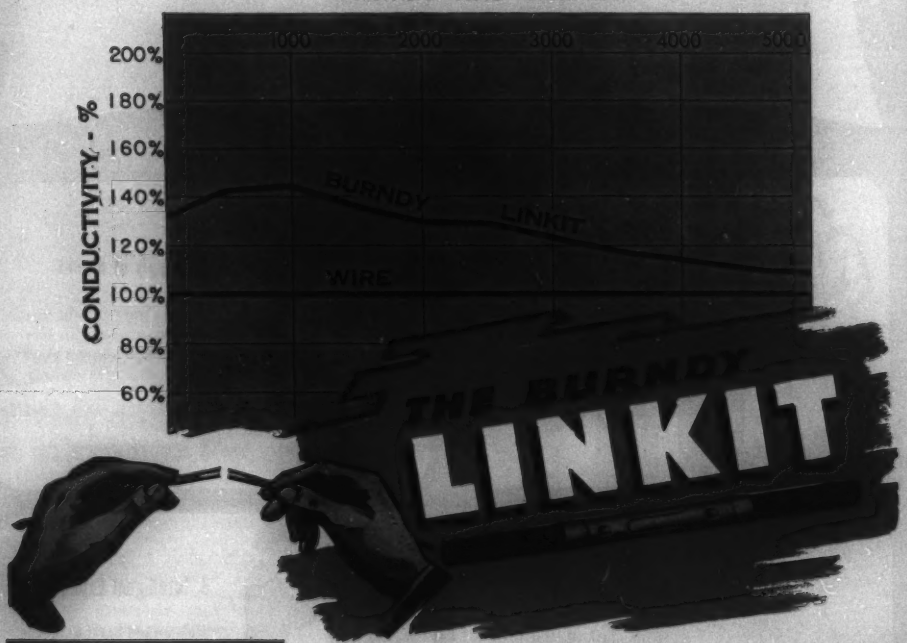
ASK ABOUT... RCA INDUSTRIAL MUSIC SERVICE

After 5000 makes and breaks

RELATIVE WIRE CONDUCTIVITY is still 110%!



Patent No. 2,199,337

THE DETACHABLE CONNECTOR WITH NO LOOSE PARTS!

This is the test that wins *instant approval* for the Burndy LINKIT! For even 100 makes and breaks would be *extreme service* for a small wire connection. Yet the LINKIT withstands *thousands*, with little effect on conductivity . . . proof of the *enduring strength* and *wearability* of its four *long* contact surfaces.

Remember, too, that each half of the LINKIT is identical . . . and there are no extra parts to loosen or lose. The halves are quickly and securely indented to the wires with Burndy HYTOOLS in the usual way. LINKITS and LINKIT lugs are available for all wire sizes from #22 up. Literature gladly sent on request.

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BURNDY *Headquarters for Connectors*

ELECTRICAL ENGINEERING

Registered United States Patent Office

DECEMBER
1943

The Cover: Wood replaced steel in this 44-kv wood-pole substation of the Public Service Company of Colorado; this design requires only a very small amount of steel and copper.

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There's a Christmas rush on telephone wires, too

Help keep war-crowded circuits clear on December 24, 25 and 26.

Please use Long Distance only if it is vital.

War needs the wires—even on holidays.

BELL TELEPHONE SYSTEM

United States Communications in the War

Communication facilities have been improved and expanded to meet wartime exigencies with a minimum sacrifice in essential services and speed. The way in which this adjustment has been made in the face of manpower and materials shortages makes one of the interesting chapters in World War II.

DESPITE critical shortages of man power and material, United States communication facilities in the war have been expanded to handle millions of words more every day—probably the greatest and fastest exchange of intelligence the world has ever known—with little disruption of the exchange of civilian information. It is true that radio "hams" have been restricted; singing telegrams and some other types of messages cannot be sent; and telephone calls without priority may have to wait; but these inconveniences are negligible when contrasted with the magnitude of the mobilization of the nation's telephone, telegraph, teletype, and radio services for war.

Military communications, themselves, form one of the biggest parts of the picture, and the great numbers of men enrolled in the Signal Corps and in the Naval Communications Service, as well as the vast amounts of communications equipment used by these services, in large measure account for the man-power and equipment shortages in civilian communications. The Signal Corps alone is now twice the size of the peacetime regular Army.

Despite the shutting off of many countries with which the United States was in daily communication before the war, the total volume of our overseas telecommunications has not decreased, and may have increased, since the outbreak of hostilities. Radiotelephone and radiotelegraph service to Central and South America, especially, have expanded, and modernization of those submarine cables still open permits the handling of the swollen war traffic—much of it government messages. Our chief source of news and intelligence from enemy and enemy-occupied countries is provided by the monitoring of their domestic and foreign broadcasts, and we in turn send out about 4,000 short-wave programs of news, propaganda, and entertainment a week to various parts of the world.

Our untrammeled domestic communications are being used as never before: so many people are communicating with so many others for various reasons connected with the war, as well as for the usual reasons, that long-distance telephone calls have doubled, and telegraph traffic has soared. But it is military communications which dominate the scene—not only because of their vastness, but because of the effect of that vastness on the rest of the picture.

Material for this article was obtained from a comprehensive report prepared by the Office of War Information. The agencies and organizations consulted in the compilation of the report were: the Federal Communications Commission, War Production Board, War Department, Navy Department, Office of the Coordinator of Inter-American Affairs, Office of Censorship, Office of Civilian Defense, Post Office Department, and various labor and industrial organizations.

MILITARY COMMUNICATIONS

Army communications are the function of the Signal Corps of the Army Service Forces, which as of June 30, 1943, numbered 280,000 men and 28,000 officers—twice the enrollment of the total peacetime regular army—taken in considerable part from the now thinned ranks of civilian communications workers. In addition, large numbers of communications personnel are distributed among the other branches of the Army as airplane and tank radio operators, and "walkie-talkie" and "handy-talkie" carriers and message runners. Many selectees without technical background but with high intelligence quotients have been given Signal Corps communications training in 50 military and 268 civilian schools, including schools and laboratories maintained by communications companies.

Mature men with specialized background are still needed by the Signal Corps; for example, the Corps could use all the electrical engineers and electronic physicists that it could find. As to equipment and parts, the Signal Corps, at the end of 1942, had slightly exceeded its procurement objectives.

As a result of certain characteristics of modern warfare—the great mobility of units, and their frequently wide separation from one another—radio communications far outweigh wire communications in this war even in the Army. Of the Signal Corps' $5,000,000,000 communications-equipment procurement program for this year, approximately 90 per cent is destined to be spent on radio.

Wire communications have the advantage of providing greater security: messages sent by wire cannot be intercepted or jammed by the enemy as easily as radio messages. But the difficulties of transporting wire and installing it over vast distances, in jungles, and other forbidding terrains are of course considerable. In combat theaters, wire communications are used down to the regimental echelon. Forward of that, communication is generally by radio. In making bridgeheads, Signal Corps troops usually are among the first to land. Radio communication is maintained between bridgehead and ship, and on shore wire is laid laterally and forward. By the time artillery is in a position to fire, wire communication has been established between the firing point and the command posts.

In Naval communications—the function of the Office

Western Electric photo

Communications provide the essential link which co-ordinates every unit in a combat theater, and enables the Armed Forces to make a simultaneous joint attack upon a given area from the air, the sea, and on land. This artist's drawing shows seven ways in which communications aid operations during combat

In (1), field headquarters is receiving orders from general headquarters through electric communications. In turn, it sends orders of its own through field telephones, teletypewriters, switchboards, wire, cable, and radio. The commander of the Air Force (2) uses radio to transmit orders to his squadron. Transport ships (3) employ battle-announcing systems to permit speedy action on commands. *PT* boats preceding the transports (4) also receive their orders by radio. In (5) the telephone is used by observation posts for the artillery to transmit messages, and by the artillery stations (6) to reply to the observation posts and to field headquarters. Tanks (7) shown here on a flanking maneuver, are followed by troops in personnel carriers. Tank commanders co-ordinate their actions with other units by radio

of Naval Communications—wire naturally plays even less of a role than in the Signal Corps, and the Navy's use of radio communications is proportionately higher.

The Coast Guard has leased five of the radiotelegraph stations on our coasts and operates them in maintaining distress watch for ships. Radio is used by the Navy not only for long-distance communications but also for short-range work between the ships and planes of a modern task force. At sea, in addition to the usual radio work, the Navy makes use of devices for the detection of enemy ships, planes and submarines. The many communications activities of the Marine Corps do not differ essentially from those of the other branches of the armed services.

Total radio production in this country which about a year ago stood at a level of $30,000,000 a month, is now up to $250,000,000 a month,—a considerably greater rate of increase than that of total war production. All such production is for the armed services, which use many other radio products besides radios for tanks, aircraft, battleships, cruisers, submarines, destroyers; field sets for the Army; public-address systems; radio compasses; direction finders; and altimeters.

In the majority of the military sets being made, receiver and transmitter are associated. Every combat tank and airplane is equipped with two or more complete communication sets. Short-wave communication is maintained between tank commanders and the individual tanks under their control, and planes communicate constantly with each other.

Some radio products are still secrets of war, and constant new developments not only have to be met by widened training in operation and maintenance, but are responsible in turn for whole cycles of research and development (usually by private companies). The war has brought about a markedly increased use of "walkie-talkies" and "handy-talkies" in various military operations on the firing line, and in intrafleet and intra-air squadron communications.

DOMESTIC COMMUNICATIONS

Domestic Standard-Band Broadcasting. During 1941, the last normal year of production, about 13,000,000 domestic broadcast-receiving sets were manufactured, and on April 22, 1942, when production ceased in favor of manufacture of military equipment, several million sets remained in the hands of manufacturers and dealers. There are still certain models on hand for purchase, all of which are well over a year old. If automobile sets are included, there are 60,000,000 receiving sets in the United States—or approximately one set for every two inhabitants. Since there are only about 31,000,000 "radio families" in the country, it is apparent that a goodly number of American families own more than one radio with which to listen to the 900 or so standard broadcast stations sending out programs almost continuously.

Many domestic receiving sets are deteriorating from age and lack of adequate service; the greatest difficulty at the present time is the securing of tubes. During the early part of this year large numbers of tubes destined for civilian use were taken over by the armed services, and, though the civilian program is being pushed, the supply is still tight. This is true particularly of tubes for the a-c–d-c sets sold in such large quantities just before the war which, fortunately in most cases, seem to be extra radios in homes.

The chief bottleneck in the manufacture of tubes is not in material but in labor; a number of manufacturers are now setting up feeder plants for tube making in areas where labor is available. The production of batteries has recently been increased to take care of the estimated 3,200,000 battery sets on farms in non-electrified areas.

The Federal Communications Commission (FCC) has made an inventory of excess radio equipment in the hands of radio stations throughout the country available for purchase by other stations. Catalogues listing this equipment and its location can be consulted by stations wishing to buy equipment directly from other stations, enabling them to avoid placing orders with manufacturers swamped by war orders.

At the suggestion of the War Production Board, FCC issued an order under which all domestic broadcast stations, without disturbance of service, have effected operating changes as a wartime means of extending transmitter-tube life. WPB simplified and standardized parts for home radios and similar equipment in order to assure wider maintenance and repair. The FCC, in conjunction with the Board of War Communications (BWC) and the Army, also has made detailed arrangements to silence any radio station in danger of being used by enemy aircraft as a radio beacon.

Man-power shortages are severe in the manufacturing, maintenance, and in the broadcasting ends of radio. Young men have been particularly predominant among the employees of the industry, and the need for their services in the Signal Corps and Naval Communications has led great numbers of them to enlist. Others, although eligible for draft deferment because of their employment in essential communication jobs, have not accepted deferment, and in some cases local draft boards have not granted it.

Despite the shortage of personnel and the tightness of equipment, domestic radiobroadcasting continues in its normal channels. The extent to which the war has affected program content is familiar to all, and, indeed, it is in certain radio programs that large sections of the American public most frequently hear the collective voice of the men at camp.

In addition to performing much wartime research in its laboratories, the radio industry has contributed much time and talent to the broadcasting of government war messages—about $140,000,000 worth during 1942.

Broadcasting stations and radio programs are responsible in large part for public understanding and acceptance of such measures as gasoline rationing, point rationing, and the Victory tax; and for the success of such campaigns as those for the use of V-mail, the purchase of War Bonds, and recruitment of glider pilots and student nurses. Every station in the country has been making between 9 and 12 announcements of war messages a day, from material furnished by various government agencies through the Office of War Information, which acts in a co-ordinating capacity.

Among the stations contributing this wartime service are the 170 domestic foreign-language stations; these broadcast programs in 30 foreign languages for a total of approximately 1,500 hours a week, and are aimed at the 25,000,000 inhabitants of the United States, most of them American citizens, who speak at least one foreign language. Of this number, there are 11,000,000 whose primary language is not English, and 2,000,000 who neither speak English nor understand it.

The preponderance of music is higher in these programs than in English-language programs, but otherwise their content of news, drama, and feature material is much the same. The chief languages are Italian, Polish, and Spanish, and the stations are heavily concentrated in the northeastern and north central states, with a number in the southwest and far west, also. There are practically no foreign-language stations in the South and the Northwest.

Before Pearl Harbor, a considerable amount of blatantly antidemocratic and pro-Axis propaganda had gone out over some of the foreign-language stations. The three existing Japanese-language programs went off the air voluntarily when the United States entered the war, but in certain other programs spokesmen continued to employ intonation, inflection and selection of news items to put across their anti-American views.

Today, three groups are concerned with maintaining foreign-language broadcast security: the Federal Bureau of Investigation, which checks personal-history statements and fingerprints of all persons engaged in production or presentation of foreign-language broadcasts; the Office of Censorship, which administers a voluntary "Code of Wartime Practices" for the stations; and the FCC, whose interest is in the operation of licensed stations in the public behalf. The stations, themselves, are responsible for all material which they broadcast, and censorship is thus on a voluntary basis, exercised either by the individual stations or through an industry committee, the Foreign Language Radio Wartime Control.

Television, Facsimile Broadcasting, and Frequency-Modulation Broadcasting. The development of television, facsimile broadcasting, and frequency-modulation broadcasting has been considerably affected by the war: in each case postponement of widened service has been forced by shortages of materials and man power. Facsimile broadcasting is still restricted to commercial use only, in connection with private point-to-point operations, but when its development and the development of frequency-modulation broadcasting are resumed, the two doubtless will be carried on jointly on a large scale. In the case of television, the FCC had limited the licensing of transmitters to prevent the freezing of the technique at a low level of effectiveness. Also, many new advances resulting from laboratory experimentation in connection with military devices will improve transmission and reception when television is allowed to develop on a commercial basis again.

Domestic Nonbroadcast Uses of Radio. Domestic nonbroadcast uses of radio are many, including use by police and fire departments, by forest-fire services, by exploration companies searching for oil or minerals, by coastal harbor stations for communication between ship and shore (now limited because of the wartime necessity for ships off shore to observe radio silence), and, on a huge scale, in aeronautics.

Since our entry into the war, certain plants manufacturing munitions and other materials have been permitted to operate their own radio stations for the purpose of communication in case of emergency. The War Emergency Radio Service, organized under the administration of the FCC with the co-operation of the Office of Civilian Defense, comprises several thousand of the country's licensed radio operators, including many of the licensed amateurs. (The operation of all amateur stations, approximately 60,000 in number, was suspended on December 7, 1941.) These operators stand ready to substitute their very high-frequency radio communication for wire service; or to supplement wire service in case of enemy bombings, other military operations, or such emergencies as flood, hurricane, or earthquake.

A number of the FCC's radio activities are directed toward the maintenance of safety at sea, a particularly crucial factor in wartime. The Commission has set up special requirements for receivers to be used on board United States vessels, and gives its approval only to those types of receivers which do not radiate signals that could attract the attention of enemy raiders. FCC men guard the special frequencies which ships use to send SOS (ship sinking) and SSS (submarine sighted) signals. When such a signal is heard the Anti-Submarine Command of the Army Air Forces is notified, and planes are on their way to the scene, sometimes within five minutes.

The routine "frequency measurement" work of the FCC has a direct bearing upon safety at sea. (This consists of checking with the utmost accuracy the exact frequency being used by various transmitters against the frequency assigned.) For example, a vessel struck by a torpedo sends out an "autoalarm" signal on the 500-kilocycle channel, and this signal automatically rings alarm bells in other vessels and at marine watch stations. If the ship's transmitter is "off frequency",

the automatic alarms on other ships may not ring and the message may go unheard.

Domestic Telephone. There are about 26,500,000 telephones in the United States—17,000,000 of which are residence phones. About 5,000,000 of them belong to the 6,300 independent telephone companies and the 60,000 rural or farmer lines; the rest belong to the Bell Telephone System. At present, it is expected that there will continue to be sufficient instruments available to take care of all essential telephone users as defined by the WPB, and to provide for what the Board calls "essential growth." If he is not on the list of essential users, however, an American who lives in one of certain areas where telephone-exchange facilities are loaded to the limit and materials are not available to enlarge them further, can no longer count on having a telephone installed promptly in his home or place of business. As in the case of radio receiving sets, the production of new telephone instruments for civilians has been stopped in favor of the manufacture of equipment for the armed services, and old-fashioned "desk" sets are being brought back into home use.

Figure 1. A midget Western Electric lip microphone concealed in the nozzle of his oxygen mask and earphones carried in his helmet enable this pilot to send and receive messages while his hands remain free for fighting. Similar microphones are used, also, by the Army ground forces

In some areas service is being "de-graded"—that is, only party-line service is being installed, and in some cases, substituted for single-party service. Both the Bell Telephone System and the independent telephone companies have expended considerable effort in conserving strategic war materials and in undertaking valuable research, and they are maintaining extensive advertising campaigns to discourage unnecessary use of the telephone that might hinder the war effort.

In the same way that users of essential service are given precedence in obtaining telephone facilities, certain urgent long-distance calls are also given priority. By order of the BWC, three classes of priority have been set up for long-distance calls vital to the war effort. Long-distance telephone traffic has nearly doubled in the last two years. At the present time, about 2,200,000 long-distance telephone calls are being made in this country per day, at an average connection speed of 3.7 minutes. Some idea of the crowding of the circuits may be gathered from the fact that two years ago the average connection speed of long-distance calls was $1\frac{1}{2}$ minutes. On the other hand, in 1916, just before this country entered the last war, average long-distance connection speed was 16 minutes. Toll calls out of Washington, D. C., alone, now average 42,000 a day, as contrasted with 24,000 a day just before Pearl Harbor.

On a country-wide average, long-distance calls still are made more frequently during the day than at night. However, in areas where there are large military camps, night calls, from 7 p.m. to 10 p.m., often are more numerous. Servicemen at the camps are usually off duty at about the same hours and consequently place their calls at the same time. This places such a burden on the circuits that delays on calls from camp pay stations often are unavoidable. In an effort to make the situation as comfortable as possible, the telephone companies now provide "attended service" at most of the larger camps and bases. The soldier or sailor can give his call to an attendant and then relax, knowing that he will be called as soon as his connection is ready.

Considerable flexibility in long-distance service is made possible by the long-distance traffic control bureaus of the Bell Telephone System, which shift circuits into localities where they are most needed at a particular time. At New York City, alone, changes of this kind are made almost 200 times a day. Some circuit shifts are planned in advance, such as the nightly shifting over of as many circuits as possible from normal business day usage to serve Army camps. Generally speaking, however, the demand for long-distance service is anything but uniform, with sudden, unpredictable surges often occurring where least expected. Whenever possible, the BWC urges the public to make its long-distance calls during off-peak hours and on Sundays.

Applications to the FCC, the BWC, and the WPB by telephone and telegraph companies for permission to expand service are carefully examined to determine whether they will fill war needs so that the use of scarce equipment and material for nonessential purposes will not result.

The telephone companies have done a good job in substituting women for men among their employees. It is estimated that seven tenths of all Bell Telephone System workers are now women, as are at least 55,000 out of the 75,000 employees of the independent companies. Even so, there are severe man-power shortages

throughout the industry, in the independent companies particularly. Traditionally low wages do not help the situation.

The over-all telephone picture thus is one of crowded circuits and of man power and material shortages, but one also of a continuation of all essential and all non-essential civilian traffic as well, except on such an abnormal day as Christmas, when the long-distance connections desired mount to a dizzying number.

Teletypewriters and Teleprinters. The use of teletypewriter or teleprinter systems, by which messages typed on one instrument are instantaneously recorded on others connected with it by wire, or occasionally by radio, has vastly expanded under wartime conditions. Government and industry are at present the greatest users of these services. The press comes third. Teletypewriter links across the country, including both leased-line and exchange services, now total nearly 2,000,000 circuit miles for the Bell Telephone System alone.

A teletypewriter exchange service makes it possible for one subscriber to be connected with another as rapidly as a long-distance telephone connection can be made. Other wire companies provide substantial additional mileage for private teleprinter systems. The railroads and pipe-line companies also make extensive use of teleprinters on their own wire lines. The Civil Aeronautics Administration leases a teletype circuit of about 63,000 miles for its aviation weather-reporting and traffic-control services. The FBI, likewise, is a big user of the teletype.

The supply of these "typing by wire" machines is far from adequate. They are being manufactured at the rate of 20 times their production before the war, but the volume of Army teletypewriter orders on hand at the present time equals approximately the total number of machines owned by the Bell Telephone System.

Domestic Telegraph. Like long-distance telephone calls, telegrams are now on a priority basis. Several classes of priority have been set up, and both private and government telegrams of direct importance to the war effort take precedence over messages not relating to the war, if such priority is requested by the sender. Formerly government messages had always been given priority, pursuant to an act of Congress.

The establishment of these priorities by the BWC was one result of an investigation of telegraph service undertaken last year by the FCC at the Board's request—an investigation carried on in 12 large cities with the co-operation of the two telegraph companies and labor unions. The investigation showed that speed of telegraph service in the United States had deteriorated considerably. In many of the cities checked, more than half the messages studied were found to be still undelivered an hour after filing, and in some cases, more than a quarter of them remained undelivered at the end of an hour and a half. Because of the presence of many new war plants and increased port activity, cities on the west coast were getting the worst service. Even war traffic in some cases was being delayed badly.

In addition to setting up priorities, the BWC issued orders establishing speed-of-service goals for telegraph messages, discontinued all nontelegraphic services, and banned the acceptance of domestic congratulatory and greeting telegrams. Earlier, the companies, themselves, had canceled all fixed-text social messages and singing telegrams.

Western Union figures for May 1943, the latest available, state that the average origin-to-destination delivery time for top priority telegrams had been reduced within the past year to 23.06 minutes, and for ordinary government and commercial telegrams, to 36.04 minutes. Preliminary FCC studies indicate that, whereas speed of service has improved since its 1942 investigation and extended delays have been reduced, the BWC goals for telegraph service are not being met yet.

Labor shortage is apparently at the heart of the problem. Traditionally low wage scales in the industry have made the present man-power situation especially acute. In January 1943, the WLB found Western Union "messenger quits" in the New York area to be running at the rate of 340 per cent a year. Elderly men and women are now being employed successfully by Western Union as messengers, and in certain cases a bounty is given to an employee of the company for bringing in another employee who remains a certain length of time. Recent national WLB awards made in the case of both Western Union and Postal Telegraph have raised wage rates substantially in both companies, and should be of great assistance in attracting employees and holding them within the industry.

On June first of this year Western Union monthly receipts showed an average increase of 70 per cent over January 1940. Some of the greatest expansions have been in private-line service between defense plants and government agencies, and in tie lines in defense areas. In general, much of the growth is due to increased business and widespread absence from home; there have been many new installations of service at camps. Members of the United States armed forces and persons sending money to them receive a substantial reduction in domestic-telegraph money-order charges. Like the telephone companies, the telegraph companies also are engaging in considerable laboratory research of benefit to military communications.

As contrasted with telephone business, most of which is local or intrastate, 95 per cent of telegraph business is long haul or interstate. Consequently, overnight telegraph business has suffered greatly during the past decade from the competition of airmail deliveries. It has suffered also from the competition of long-distance telephoning, since these rates have been decreased substantially.

The hope for continued large-scale existence of telegraph business would seem to lie in an increased mecha-

nization, which will lower costs and thus permit effective competition with other forms of rapid communication. Messenger boys will doubtless occupy less than their present place in any large-scale postwar communications system.

INTERNATIONAL COMMUNICATIONS

International Broadcasting. All 14 of the country's privately owned short-wave broadcasting stations (one of them built since Pearl Harbor), and eight commercial communications transmitters formerly used for point-to-point telephone, program, or radiophoto service, have been leased jointly for the duration of the war by the Office of War Information and the Coordinator of Inter-American Affairs (CIAA). Twenty-two new transmitters are now being added, and on their completion, the considerably lower-powered commercial transmitters will be dropped.

The programs which the two federal agencies broadcast internationally constitute an integral part of American psychological warfare. OWI's international message, the "Voice of America," is aimed at five listening groups: enemy areas, Axis-occupied areas, neutral countries, the United Nations, and Allied-occupied areas. It is heard 24 hours a day in more than 40 languages and dialects in a total of more than 3,200 quarter-hour productions a week.

To supplement this coverage, more than 100 programs a week are picked up by the British Broadcasting Corporation and rebroadcast by medium wave. Also, many transcribed programs are shipped abroad. Some of the "Voice of America" programs are developed by the National Broadcasting Company and the Columbia Broadcasting System from scripts prepared by various government agencies for which the networks provide the talent and the direction.

There are many indications—some of which must remain secrets of war—as to the effectiveness of the "Voice of America" in combating Axis propaganda and spreading the meaning of our cause. The day after the invasion of North Africa, for example, when it was of paramount importance to reach French listeners in North Africa and France, the Berne correspondent of the New York *Times* cabled his paper: "American broadcasts are listened to day and night, and it is certain a great impression has been made. The French may be skeptical but they are also sentimental, and President Roosevelt's reference to 'France eternal' dimmed many an eye."

Programs in French are broadcast 22 out of every 24 hours. Reception is generally very good throughout France, and a London intelligence source, familiar with French underground papers, estimated recently that at least half of their news and feature items were taken from United States broadcasts.

A dispatch from Stockholm on May 8, 1943, to the Washington *Star* declared: "Paul Joseph Goebbels has been fighting a losing battle here, where American propaganda has slowly overwhelmed the Nazis' energetic and carefully planned effort to convince the Swedes that Germany has right on her side and is bound to win the war."

In French Guiana and Martinique, OWI broadcasts were an important influence in bringing about the downfall of the pro-Vichy governors and the alliance of the colonies with the United Nations. From the angry reaction of Axis home radios, which frequently go to great lengths to answer broadcasts from the United States, it is apparent that OWI has numerous listeners in Germany and Italy. There are probably fewer in Japan, but even thence comes evidence that some Japanese, both at home and overseas, listen to America's "voice."

Since November 30, OWI has maintained constant two-way radio contact with Algiers; and North African stations, both medium- and short-wave, relay many United States programs to Europe on a daily basis.

In this hemisphere, OWI serves the three South American colonies of foreign powers and the West Indies colonies. The CIAA, on the other hand, works with all 20 of the independent Latin-American republics, sending out a total of 550 short-wave programs a week, which range in length from five minutes to half an hour. Of these, 153, which are aimed at Brazil only, are in Portuguese, 186 are in English, and 211 in Spanish. Most CIAA programs are produced by NBC and CBS, under contract.

Since its programs do not go to enemy or enemy-occupied countries, where short-wave broadcasts are the only means of communication, CIAA is able to use other forms of communication to a greater degree than OWI: some of its programs, for example, are sent out of the United States by radiotelephone and rebroadcast locally, and many others are produced locally in the Latin-American countries.

CIAA makes greater use of transcription than does OWI. Its short-wave broadcasting is done over the same stations used by OWI, but its peak of activity comes at a different time; 5 p.m. to midnight, Eastern War Time, OWI's slack period, is CIAA's period of greatest activity. CIAA broadcasts about eight hours a day. Its listeners abroad are not furtive, like OWI's. They can listen as long and as openly as they please. It is possible to make the average broadcast longer, to send over the air large-scale examples of our popular and intellectual culture, and to familiarize our Latin-American neighbors with large aspects of our lives and institutions.

For about an hour each night, CBS and NBC networks of local Latin-American stations—150 stations in all—pick up CIAA broadcasts on time paid for by CIAA, and carry them to vaster audiences than can be reached directly by short wave. Surveys show CIAA programs to be well received by large audiences. CIAA

Western Electric photo

Figure 2. A field telephone being used to direct fire-control commands on maneuvers in northwest United States

broadcasts news every hour on the hour, sending out a total of three hours of news a day. News commentators from the Latin-American countries, stationed permanently in New York, broadcast regularly.

In general, CIAA's broadcasting schedule bears a greater resemblance to a domestic network than does OWI's. There is a good deal of music and amusement, and less of the special intense kind of information and encouragement called for by the living conditions of much of OWI's audience. Each of these agencies fits its programs to its special job. Like OWI, CIAA broadcasts programs of news and entertainment to our servicemen overseas.

Foreign Broadcast Intelligence Service. Although a certain number of Americans—especially Americans born abroad—listen to short-wave programs broadcast from foreign countries, the total American audience for such broadcasts is not large even in wartime. Americans appear to be satisfied with the variety offered by domestic programs and to prefer the quality of reception on local stations. Nevertheless, regardless of how many Americans make a practice of listening to them, short-wave broadcasts from Germany come to this country 11 hours every day and from Japan $4^1/_2$ hours. Other short-wave programs come from our Allies, our Latin-American neighbors, and many other countries.

Because the enemy and enemy-conquered countries have cut off the regular channels of rapid news communication (diplomatic staffs, press representatives, cable news service, travelers), enemy and neutral radiobroadcasts for domestic and foreign consumption are our chief source of foreign news and intelligence. To keep government agencies and the armed services informed of the contents of these foreign broadcasts, the Foreign Broadcast Intelligence Service (FBIS) of the FCC covers about 2,500,000 words a day, summarizes and digests the broadcasts, records the more important of them, translates them from 35 or more languages and dialects, and finally sends on the intelligence which they contain to the government departments concerned. It is thus possible to know the enemy's propaganda lines to their own people, to neutrals, and to the United Nations, and to neutralize or combat them. The OWI, for example, checks the FCC interceptions of German short-wave propaganda against what the Germans are saying to their own people, or with contradictory statements which prove the falsity of the stories that they broadcast to America.

The FBIS divides the world into three parts:

1. Broadcasts from Asia and the Far East are listened to from Portland, Oreg., and San Francisco, Calif.
2. Friendly broadcasts from Latin America are received at Kingsville, Tex.
3. International broadcasts from Europe, Africa, and the Middle East are intercepted in Washington, D. C., and Puerto Rico, and home broadcasts are heard near London, Eng.

The FBIS forms part of the widespread United Nations network of radio interception, co-operating especially with OWI and with British and Dominions interception services all over the world with interchange of findings. The FBIS monitors for the Army all messages from American prisoners of war forwarded by Axis radio. These are forwarded to the War Department for notification of relatives. Details of the bombing of Tokyo—announced on Japanese broadcasts to home listeners—were first learned over the monitoring radio in the Portland, Oreg., receiving station.

Submarine Cable. Although the war has interrupted cable communication services of American companies to continental Europe and to Far Eastern points, direct facilities are still available to the United Kingdom, Eire, Portugal, Gibraltar, the Azores, Hawaii, and Midway. In addition, there is complete Western-Hemisphere cable service, uninterrupted by the war, to the West Indies and along both coasts of South America; and the submarine cables to Alaska have been modernized to carry heavy traffic.

About 66 per cent of international-communication telegraph traffic to Europe, the Near East, and Africa is handled by cable, as is about 81 per cent of the traffic to South America and about 30 per cent of trans-Pacific traffic, including traffic via British cables from Canada.

(The reason for this low percentage of trans-Pacific cable traffic is that only two direct cables exist to Australia—those from Vancouver; all other trans-Pacific cable traffic, except for the American cable to Hawaii and Midway, must go via the Mediterranean Sea or the Cape of Good Hope and India.) The rest of the traffic is handled by radiotelegraph.

In general, it may be said that, computed by the number of messages, 65 per cent of the world international communication telegraph traffic is handled by cable and 35 per cent by radio. The speed of the two services is the same between points to which there are direct cable circuits; when relays are necessary, radio is faster.

One of the reasons for this continued predominance of ocean cable in the face of radio competition is habit—cables have always carried the bulk of direct business traffic. On those lines which are still open, business has greatly increased, and the traffic is largely in government messages with a priority known as "government urgent." The State Department, the Army, the Navy, and other government departments lease their own time on cable circuits, some of them for 24 hours a day, and others part time. The adoption of the varioplex channeling system—widely used on land telegraph lines—on the cables to England makes it possible to send as many as 12 messages simultaneously over a single cable.

Another reason for the continued popularity of submarine cable is the secrecy which it affords in time of war. It is difficult to tap an ocean cable. Plans exist by which increased radiotelegraph facilities will be made available in case of the cutting of any of the cables by the enemy. Cable repairs, difficult in the best of times, present increased hazards at present. Not only are there shortages of many materials needed in repair work, but also cable-repair ships now require naval escort. Several British cable ships (most cable ships are under British registry) have been sunk in the North Atlantic while engaged in their work or en route to it.

Radiotelegraph. About the middle of 1942, all domestic radiotelegraph traffic, with the exception of the transcontinental circuits which handle the relay of international traffic, was ordered discontinued by the BWC because domestic messages carried by this medium could be intercepted easily by other countries. Actually, only about $1^1/_2$ per cent of domestic telegraph messages had ever been carried by radio, and parallel service was offered by the wire telegraph.

Although the entry of the United States into the war brought about the discontinuance of direct radiotelegraph circuits with Axis countries and countries occupied by the Axis, international radiotelegraph service to and from the United States has been extended greatly since the beginning of the war. Prior to Pearl Harbor, for example, radiotelegraphic communications between the United States and Australia were relayed via Montreal. Now the traffic is routed over direct circuits. Since 1939, new direct radiotelegraph circuits have been established to Egypt, Iceland, Paraguay, Bolivia, New Caledonia, Greenland, New Zealand, Iran, French Equatorial Africa, Belgian Congo, Algiers, British Gold Coast, Bermuda, Afghanistan, and to numerous points in the European and Asiatic Union of Soviet Socialist Republics and unoccupied China.

To each new point to which service is inaugurated, only one company is permitted to operate. Shortages of materials and the limited number of long-range channels available for international communications rule out parallel, competing circuits. Civilian use must be held to a minimum if the greatly increased number of essential military services is to be handled in the already crowded radio spectrum.

Expeditionary Force Message Service. In June 1942, special low-priced cable and wireless message rates were made available to members of the American Expeditionary Forces and persons communicating with them. A combination of any three of 104 fixed texts, designed to cover nearly all occasions, offers the sender a low message rate—60 cents or its equivalent in other currencies. This is a two-way, purely overseas service. It is available at practically every overseas base.

Overseas Telephone. Before the war, the United States was connected by direct radiotelephone service with all major countries and strategic areas throughout the world. The first to be shut off from us were the German-occupied countries in Europe. Then, after

OWI photo

Figure 3. This lookout station banked with sandbags shelters one of the blinker lamps used in United States coastal defense to guide incoming ships to shore

Pearl Harbor, service to Berlin, Rome, and Tokyo was suspended, and subsequently, service to Java and the Philippines was discontinued when these countries were occupied by Japan.

During the past year, radiotelephone service has been extended to Surinam, Dutch Guiana, and to Recife, Brazil, via Rio de Janeiro. Plans for service to the Soviet Union and to several additional islands in the Caribbean are under way. Because of the tremendous increase in radiotelephone traffic to Central and South America, Hawaii, Puerto Rico, and Panama, additional circuits have been established to those points. Radiotelephone traffic between the United States and Panama has augmented more than 200 per cent since Pearl Harbor, and between the United States and Hawaii, over 300 per cent. This growth in inter-American calls has more than offset the loss of calls to other parts of the world. Today the total radiotelephone-message volume is about half again as large as before Pearl Harbor.

Except for the Bahamas and Jamaica, personal radiotelephone calls may be made between any two points in the Western Hemisphere. For the rest of the countries with whom telephone connections are still open, however, the following BWC regulations are in effect:

1. Except for American press calls and radiobroadcast programs, no nongovernmental business or personal radiotelephone call can be made to or from any foreign point outside the Western Hemisphere other than Great Britain, or to and from the Bahamas or Jamaica, unless the call is made in the interest of the United States or the United Nations, sponsored by an agency of the United States government and approved by the Office of Censorship. Nongovernmental business or personal radiotelephone calls are not permitted between the United States and Great Britain.

2. No calls of any nature over the radiotelephone circuits under the jurisdiction of the United States, no matter where such calls may originate, unless they are sponsored and approved as indicated in paragraph 1, shall be permitted to, from, or on behalf of the following 13 countries: Egypt, Finland, France, Iceland, Iran, Ireland, Latvia, Lithuania, Portugal, Spain, Sweden, Switzerland, and Turkey.

To prevent overseas telephone conversations from being overheard by curious listeners, voices are "scrambled" by various radio devices as they go over the circuits and "unscrambled" when they arrive at their destination. Ship-to-shore telephones on ocean-going vessels are no longer employed for public use as they would betray ship locations to the enemy.

POLICING THE ETHER

Since the early days of radio regulation, monitoring has been necessary to make sure that radio transmissions obey ordinary ether-traffic rules. Various types of radio transmissions are assigned particular ether lanes in which to travel. If one signal strays over its assigned "white line," there is collision with other services and resultant confusion. Likewise, if a transmission appears in the ether paths without identifying call letters, it is as quickly spotted as an automobile without license plates traversing a land highway.

At present, the Radio Intelligence Division of the FCC is particularly alert for signals which might prove to be illegal. Since July 1940, over 2,000 cases have been investigated and many operators have been convicted. Also detected have been many radio circuits operated by enemy agents.

For its policing work, the Radio Intelligence Division maintains 12 primary monitoring stations, 90 secondary monitoring stations (one or more of which are located in each of the 48 States and in all territories and possessions), and three radio intelligence centers at Honolulu, San Francisco, Calif., and Washington, D. C. Monitoring stations are usually located in isolated places far from the nearest town in order to procure ideal listening conditions.

Furthermore, 30 mobile units of two men each now maintain a continuous automobile patrol of the entire 5,000-mile coast line of the continental United States. These coastal units are particularly on the watch for any radio transmitters on shore which might be communicating with an enemy ship at sea relative to the departure, location, or cargoes of departing vessels. The system is so organized that a clandestine signal receivable anywhere in American territory can be traced.

When an intruder is detected in the ether lanes, either by one of the Division's monitoring stations or by a broadcaster who reports it, direction-finding apparatus is called into play. Three or more monitoring stations collaborate in getting a bearing on the signal in question. Their beams are plotted on a map, and eventually the lines will cross. This point of intersection, marks the general location of the origin of the transmission.

The final task of running down the offender is performed by monitoring officers—men highly skilled in radio technique—using automobiles which are fitted with the latest and most efficient type of detection equipment, including direction finders, all-wave receivers, and recorders. All this apparatus can be operated from the car's battery, or, upon being removed from the car, from the power supply of a dwelling, store, or tourist camp. Operation of the mobile equipment follows much the same procedure employed by the monitoring stations in the first instance. Bearings finally fix the exact location of the transmitter in question. Even if the hunt narrows to an apartment house, hotel, or other large building, a monitoring officer, by using a device carried in his hand or in his pocket, can proceed from floor to floor and from door to door until he determines the exact room in which the equipment is being used.

CONCLUSION

The impact of vastly expanded military communications, swollen civilian wartime traffic, and other purely wartime considerations is to be felt in every branch of communications. Man power, materials, service, and as regards broadcasting, program content, all testify to the fact that "this is war."

Metallurgical Problems Arising From the Use of Copper in Electric Equipment

E. R. PARKER

Pure copper is used extensively in electric equipment because of its high conductivity, but its low tensile strength and its high specific gravity make it generally unsuitable for structural purposes. The author describes the problems involved in adjusting the various properties of copper so that the greatest efficiency in the use of the equipment can be achieved.

COPPER has played the leading role as an electric conductor ever since the inception of the electrical industry early in the 19th century. Galvani in 1786 used copper when he noticed the curious behavior of frog's legs hung by copper hooks from an iron railing. His experiments excited much interest and led to the development of the first electric battery by Volta in 1799. Volta's battery employed copper as an electrode material. After 1800, the study and application of electricity made rapid progress. By 1809, John Children had built a battery with 20 pairs of copper and zinc plates, each over 15 square feet in area. With this battery he measured the conductivity of various materials, and proved that copper was superior as an electric conductor.

One of the earliest practical applications of electricity was for communication. In 1837 the first telegraph was put into commercial use. Greater power than was available from batteries was needed for the extensive commercial applications. The electromagnetic investigations then in progress led to the discovery and development by Faraday of the first generator, which he built in 1831. As a result of Faraday's work, power-driven generators were in commercial use within a few years. Since then, the electrical industry has grown to such an extent that huge machines capable of generating 200,000 kva are now in use.

In normal times the electrical industry is the largest user of copper. Table I gives the estimated use of copper in the United States for the period 1936–40. These figures include all production and use of either pure or alloyed copper. About 35 per cent of the total copper production is consumed by the electrical industries. Because of the large use of copper in electric equipment, many metallurgical problems arise which are of paramount importance in determining the performance of the equipment. The object of this article is to indicate briefly some of the important metallurgical problems.

Pure copper is used extensively in electric equipment because of its high electric conductivity. The tensile strength of copper is low and its specific gravity is high, so that it is generally unsuitable for structural use. However, some of the alloys of copper exhibit exceptionally good mechanical properties (for example, beryllium copper) and are widely used for structural purposes.

The tensile strength of soft copper is about 31,000 pounds per square inch, and, before fracturing, it elongates approximately 40 per cent. Hard-drawn copper has about twice the tensile strength of soft copper, but the elongation is only a few per cent.

Copper used for electric conductors must be of high purity. Typical compositions of tough-pitch and oxygen-free high-conductivity copper are given in Table II. The total of the metallic impurities in both types of coppers is only about 0.01 per cent. The need for such high purity becomes obvious when Table III is studied. Small amounts of impurities may greatly reduce the electric conductivity of copper and thus limit the efficiency of electric equipment in which the material is used.

The conductivity of high-purity copper is affected strongly by cold working. For example, when the cross-sectional area is reduced 85 per cent by cold drawing, the conductivity drops from 102.3 to 100.0 per cent. Consequently, annealed copper is used whenever high conductivity is desired.

Table I. Estimated Use of Copper in the United States, 1936–40, in Short Tons*

Use	1936	1937	1938	1939	1940
Electrical manufactures	164,000	212,000	150,000	185,000	247,000
Telephone and telegraph	26,000	40,000	30,000	39,000	49,000
Light and power lines	72,000	83,000	62,000	67,000	74,000
Wire cloth	6,500	6,800	6,000	8,000	9,200
Other rod and wire	90,000	102,000	60,000	95,000	120,000
Ammunition	11,900	14,100	12,500	14,500	26,000
Automobiles	108,000	112,000	55,000	85,000	103,000
Buildings	71,000	70,500	67,500	89,000	102,000
Castings	39,000	40,000	31,000	33,000	35,000
Clocks and watches	3,400	4,000	3,000	4,000	4,400
Copper-bearing steel	3,900	4,600	2,600	4,200	4,700
Radiators, heating	2,000	2,100	2,000	3,600	2,900
Radio receiving sets	24,000	23,100	21,000	27,000	32,000
Railway equipment	4,000	7,100	1,700	2,700	5,700
Refrigerators	15,000	13,500	6,700	10,000	10,500
Shipbuilding	5,000	6,400	6,000	8,500	8,700
Air conditioning	6,400	7,200	6,000	6,000	6,000
Other uses	65,300	66,600	46,200	67,600	81,500
Manufactures for exports	31,600	45,000	38,800	51,900	148,400
	749,000	860,000	608,000	801,000	1,070,000

* From Minerals Yearbook Review of 1940.

Essential substance of a conference paper presented at the AIEE Pacific Coast national technical meeting, Salt Lake City, Utah, September 3, 1943.

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Table II. Typical Analyses of Oxygen-Free and Tough-Pitch Coppers Used for Electric Conductors

Elements	Oxygen-Free Copper	Tough-Pitch Copper
Silver	0.0022	0.0015
Iron	0.0015	0.0007
Lead	0.0009	0.0001
Sulphur	0.0023	0.0013
Arsenic	0.0004	0.0003
Nickel	0.0008	0.0002
Bismuth	0.0001	0.00001
Tellurium	0.0002	0.0001
Selenium	0.0003	
Manganese	0.003	
Tin	0.00005	Nil
Antimony	0.0009	0.0002
Oxygen	0.00000	0.035
Copper (balance)	99.988	99.961

Table III. Effect of Impurities on the Conductivity of Copper*

Per Cent of Element Present	Conductivity of Copper Containing							
	Cadmium	Silver	Tin†	Nickel	Tellurium	Antimony	Cobalt†	Iron†
0.001	102.3	102.3	102.1	102.2	102.1	102.1	101.8	101.5
0.01	102.3	102.2	101.4	101.3	101.0	100.6	98.1	95.0

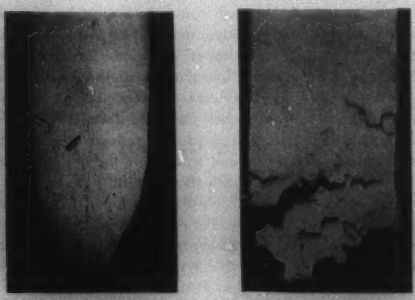
The conductivity of spectrographically pure copper is 102.3.

* From data by Smart, Smith, and Phillips (see references 1, 2, and 3).

† The tabulated data are for *oxygen-free* coppers; in oxygen-bearing coppers, tin, cobalt, and iron are present as oxides and, therefore, do not affect the conductivity.

Small amounts of impurities also have profound effects on the annealing characteristics of copper. This has long been known, but some recent quantitative data by Smart, Smith, and Phillips[1,2,3] are worthy of attention. They added various amounts of other elements to spectographically pure copper and studied the annealing characteristics of these alloys. Some of the results they obtained are summarized in Table IV.

A survey of the table will show the great effect of some impurities on the softening temperature. Particularly outstanding is the effect of tellurium. As little as



(*a*) (*b*)

Figure 1. Low-temperature transcrystalline fracture of a copper bar (a) and high-temperature intercrystalline fracture of a copper bar (b) magnified seven times

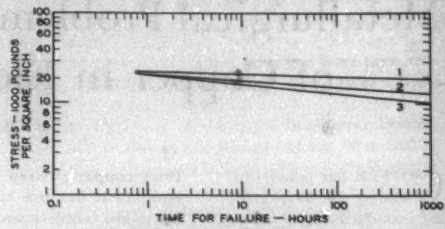


Figure 2. Curves of stress versus life for three types of copper tested at 200 degrees centigrade

1. *Tough-pitch copper containing silver*
2. *Tough-pitch copper*
3. *Pure copper*

0.001 per cent is sufficient to raise the softening temperature about 80 degrees centigrade.

In the manufacture of electric equipment, it is desirable to be able to adjust the various properties of copper so that the most efficient use can be made of the equipment of which the copper is part. Generally, high conductivity is essential for high efficiency, and the allowable quantity of impurities thus is automatically limited. Certain applications of copper require operating temperatures above those normally employed. Under the influence of stress at high temperatures, copper often breaks with very little elongation. The apparently "brittle" failure follows the grain boundaries of the copper instead of going across the grains as a normal ductile failure does. Figure 1 shows both a short-time ductile transcrystalline fracture and a low-ductility long-time intergranular fracture. The intergranular type of failure can occur in equipment operating at temperatures above 125 degrees centigrade whenever the copper is subjected to prolonged loading. At higher temperatures, such fractures occur with lower loads and in shorter times, often without warning or noticeable deformation. At times these intergranular failures have caused much

Table IV. Effect of Impurities on the Softening Temperature† of Copper*

Per Cent of Element Present	Softening Temperature in Degrees Centigrade of Copper Containing							
	Cadmium	Silver	Tin‡	Nickel	Tellurium	Antimony	Cobalt‡	Iron‡
0.001	160	142	150	140	220	160	142	145
0.01	310	205	315	145	370	320	160	155

The softening temperature of spectrographically pure copper is 140 degrees centigrade.

* From data by Smart, Smith, and Phillips (see references 1, 2, and 3).

† The softening temperature reported in the table is the temperature to which the copper, after being reduced cold 75 per cent in cross section, must be heated for one hour to reduce the tensile strength to a value half way between those of the hard-drawn and annealed conditions.

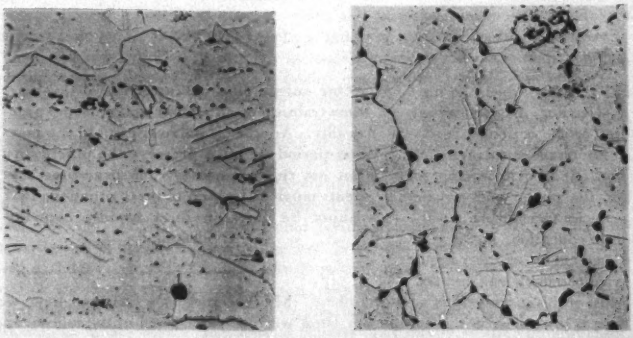
‡ The tabulated data are for *oxygen-free* coppers; in oxygen-bearing coppers, tin, cobalt, and iron are present as oxides and therefore do not affect the softening temperature.

trouble in the manufacture and in the use of some electric equipment. Such failures can be eliminated by a judicious balance of the impurities present in the coppers.

Tests of the type plotted in Figure 2 are useful in evaluating the influence of various elements on the high-temperature strength. Bars of each type of copper were held under constant load at the testing temperature, and the time for failure was noted. A series of such tests at various loads yields the "rupture curves" plotted in Figure 2. As the stress is lowered the life becomes longer. However, the ductility decreases, and the type of failure changes from the transcrystalline type characteristic of short time and low temperatures, to the intergranular type characteristic of long time and high temperatures. High-purity copper is very weak at 200 degrees centigrade. Commercial tough-pitch copper, which contains about 0.01 per cent metallic impurities, is considerably stronger. The addition of 0.039 per cent silver to the tough-pitch copper greatly improves the high-temperature strength and practically eliminates the undesirable intergranular fractures. Small quantities of other elements such as cadmium and manganese[4] also greatly improve the high-temperature strength without lowering appreciably the conductivity. Study of the high-temperature properties of copper indicates that small amounts of certain elements greatly increase its strength at high temperatures. The maximum operating temperature is now limited mainly by the available insulating materials.

Under present emergency conditions it is often necessary to overload transmission lines. The question naturally arises, what is the maximum temperature at which the transmission lines can be operated without long-time high-temperature fractures occurring? The answer differs for each copper and each installation, but in specific cases the question is being answered successfully by means of tests similar to those recorded in Figure 2.

The foregoing discussion has been concerned mainly with the materials having good high-temperature strength, a factor which seems to be associated with high softening temperature. However, there are many applications where a high softening temperature is very undesirable. One such instance that is frequently encountered is in the annealing of hard-copper wire during the baking of the enamel in the enameling process. The wire is run continuously through the enamel and then directly into the baking oven. If the baking and softening can be done simultaneously, soft-copper wire, necessary for certain applications, can be produced more rapidly and cheaper than if a separate annealing operation were necessary. The baking temperature is limited by the enamel, which must not be "burned" in the operation. Small amounts of impurities, particularly tellurium, antimony, and cadmium, prevent copper from softening. Consequently, great care must be taken to remove these elements during the copper-refining process whenever the copper is to be used in the enameling process. If random batches of copper are used, it is sometimes necessary, before processing, to separate those coppers with high-softening temperatures. These are used, then, for other purposes.



(a) (b)

Figure 3. Tough-pitch copper (a) and tough-pitch copper embrittled by heating in hydrogen (b) magnified 250 times

Another difficulty often encountered in the electrical industry is hydrogen embrittlement of tough-pitch copper.[5] Whenever copper containing copper oxide is heated in an atmosphere containing hydrogen, the hydrogen may diffuse into the copper, unite with the copper oxide and form water vapor which cannot escape. The water vapor expands and causes large holes to form, thus embrittling the copper. Embrittled copper, shown in Figure 3, is very weak and has extremely low ductility. Consequently, contact with hydrogen must be avoided in the fabrication of tough-pitch copper. Oxygen-free copper is used whenever the copper must be heated in contact with hydrogen.

An interesting problem that as yet has not been solved is that of the copper-oxide rectifier. The metallurgical requirements of copper for good rectifiers are not clearly understood. Some coppers are good; others for no apparent reason are bad.

In conclusion, it should be pointed out that most of the metallurgical problems connected with the use of copper

in electric equipment are clearly understood. However, new designs and uses of equipment undoubtedly will bring forth many new problems to be solved through metallurgical research.

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Practical Education in Wartime

PHILIP W. SWAIN

LEST my subject be misleading, may I state that this article is neither a survey nor a statistical presentation. It is not an attempt to list the public and private agencies specializing in wartime education, nor is it a classification of the various types of schools and courses. Most of this machinery is a passing phase. My concern here is to review, in the light of our latest wartime experience and with an eye to the future, certain personal views and convictions about the objects and methods of education. Let us reconsider the two basic questions:

"One outstanding characteristic of this wartime training or education is its extreme practicality. Another is narrowness. In the postwar period we must preserve the practicality but not the narrowness, for peacetime students must be trained to meet situations that cannot be foreseen in a rapidly evolving civilization."

1. What is worth learning?
2. What is the best way to learn it?

Not now a professional educator, I speak as a man who still makes a hobby of education. At various times I have done practical teaching—have tutored physics, taught power engineering and mechanics of materials, drilled soldiers in the last war, instructed artillery officers in ballistics and orientation, and more recently, have given a few university courses in business journalism. All through these years, when I haven't been teaching, myself, I have been watching other teachers, studying their results, and pondering the aims and methods of education. As a result, gradually I have acquired certain strong convictions, which I shall set forth for your consideration.

There can be no better time than now to discuss education, while the explosions of war are shaking all our institutions of learning and teaching. Everywhere the cement of educational tradition is cracking. Teachers, administrators, programs, and methods are forced to justify themselves by their works, rather than by their forebears. Right now, before we settle back into the old routine, is the time to study what is being done, and to get set for the great postwar educational advance.

My thoughts and comments mostly look ahead, because already we are finding out how to educate for *this* war, and those whose job that is are doing it fairly well in the colleges and technical institutes, in the vocational and public schools, in the training camps, at sea, and on the battlefields. One outstanding characteristic of this wartime training or education is intense practicality. Another is narrowness. In the postwar period we must preserve the practicality, but not the narrowness, for peacetime students must be trained to meet situations that cannot be foreseen in a rapidly evolving civilization.

From recognizing the need for breadth, some persons have "sailed through the air with the greatest of ease" to the unwarranted conclusion that the traditional liberal-arts course, long on the humanities and short on physical science and vocational subjects, is an excellent all-round preparation for life in the world ahead. As a Bachelor of Arts graduate, myself, I must register violent disagreement with this view.

CULTURE VERSUS VOCATION

Strangely enough, the battle between culture and vocation is still being waged, and on false premises, although the classicists have lost much ground since those distant days when every gentleman scholar was expected

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Essential substance of a paper presented at the Midwest Power Conference, Chicago, Ill., April 8, 1943.

to master both Latin and Greek—the days when no self-respecting university would prepare students for a vocation other than that of doctor, lawyer, parson, or gentleman of leisure.

Since the very meaning of culture is often debated, let me define it as enlightenment, discipline, and refinement, obtained by mental and moral training.

I believe in the maximum cultivation of the mind and spirit, but do not conclude, therefore, that the six years I devoted to the study of Latin and the five to Greek were a justifiable allocation of time and human energy—not even from the cultural angle. I speak with feeling, for I gained my machine-shop experience during the summers between terms of Greek study. I am positive that the shop experience had more purely cultural value to me than the Greek, to say nothing of its relative vocational practicality.

You must pardon me for appearing to shout at a man of straw. To study or not to study Greek is no longer an educational issue in America. That battle was lost decades ago. But the war of curricula—culture versus vocation—goes on. The overlooked truth is that all sound vocational training is, in itself, highly cultural. It is equally true, of course, that certain subjects with little vocational application have such great cultural value as to justify a big place in the curriculum, but let them hold this place because of something better than a certificate of vocational uselessness.

I would classify elementary physics, chemistry, mathematics (mainly arithmetic), practical English (training in reading, writing, and speaking the language), practical economics, typewriting, and elementary drawing as being definitely of vocational value to most Americans on most jobs. Such other subjects as shop-work, biology, and advanced sciences and mathematics, have vocational value for specific groups. Let these subjects be selected first on the basis of their vocational usefulness to the student concerned. Each one will then do double duty, because each one is highly cultural, also.

Next, let's put into the curriculum those other subjects most essential for sound citizenship, such as geography, history, civics, and general economics. These, too, are also cultural, and thus again do educational double duty. Then, if there is time, one should add certain subjects that will give the greatest return in human satisfaction though essential neither to occupation nor good citizenship. I have in mind, particularly, English literature, modern languages, music, and art.

I think it will be conceded, generally, that the only proper object of education is to prepare the student to live a happy and useful life. That is why truly vocational training automatically must take first place as the prime essential for both usefulness and happiness. Let us never forget the joy of doing a job well. Let us never imagine that it is more cultural to live on relief than to draw an adequate pay check, or that those who do not know how to provide food and clothes for themselves ever will have much opportunity to live the higher life.

As to subject matter, my fundamental conviction is that primarily, education should be vocational; secondarily, a training for citizenship; and thirdly, purely cultural to the extent of the remaining available time and facilities; and that all three of these are cultural in the broad sense of the word. In round figures, sound education is 80 per cent practical and 100 per cent cultural.

After subject matter comes the great question of method. Examples of good teaching and good learning are to be found here and there, but inept teaching and bad study habits are more common on all levels of education from kindergarten to university graduate courses. Consider, for example, the so-called "lecture courses" that long have been an educational scandal, particularly in liberal-arts colleges. I am referring to courses in which the professor stands before and lectures to a large group of students three or four times a week with no student participation other than listening and note taking—no laboratory work, and no conferences. The professor stands up there and talks, and the students, like sponges under a dripping faucet, are supposed to swell up gradually with the moisture of knowledge.

"Lecture courses" may be justified in the case of such intangible subject matter as philosophy, ethics, human relations, and politics, where some great and mellow personality can broadcast atmosphere, attitude, and human lore from his lecture platform. To attempt to teach physics, chemistry, mathematics, or any precise discipline or practical skill *primarily* by lectures is nothing short of educational asininity, in my opinion. One cannot master such subjects by listening to someone else talk. In these fields one can never acquire an education except by rolling up his own sleeves, burning his own midnight oil, solving his own problems, sweating over his own laboratory project, asking questions, and grilling and being grilled by a smart teacher in the give-and-take of conference and recitation.

Good teaching keeps the learner *doing* something. Education not accompanied by muscular action doesn't stick, and, therefore, is a shoddy product. I believe in drill, drill, and more drill; things heard and tried but once are soon forgotten. Superficiality is the bane of much modern education, particularly in those high schools and colleges that try to "cover a lot of ground." We need far more thoroughness in education.

Note that I did not say "completeness." Many high schools today are so crowded with required courses that the dizzy students get nothing thoroughly except mental indigestion. If the number of courses cannot be cut, then the content of individual courses should be reduced.

Let's shorten the history book and really learn what's left. Let's drop some of the secondary information at the end of the trigonometry book to make certain the

student is amply drilled in what is really important—the use of sines, tangents, and cosines in measuring and laying out angles. The same suggestion applies to physics, chemistry, and English literature. In each field the specialists are trying to cram so much detail into young heads that nothing is retained.

I have expressed a low opinion of any attempt to teach precise scientific and vocational disciplines by courses devoted predominantly to lectures. To the extent that one cannot learn by lectures, how can one learn? In my opinion one can learn best by reading and by doing.

First, let's consider books. Wherein is the reading of a book any better than listening to a lecture? It won't be if you don't know how to read. The worst thing about a lecture is that the talker plunges ahead without knowing whether you, the listener, are dragging behind or running a mile ahead. If one reads a textbook straight through without stopping for breath, one might as well be listening to a lecture. But it isn't necessary to study that way. The man who knows how to study any exact scientific and logical discipline out of a book pauses every few minutes to make a sketch, spot a location on the map, look up a word in the dictionary, or solve a numerical problem. He does something; he uses many muscles, and he fences mentally with the author. This activity seems to be a sort of waterproof adhesive that cements, that attaches the learning to the man so that it will not wash off with the first rain.

On the whole, it seems that the writers of educational books are a more serviceable tribe than the givers of lecture courses, but they are not above criticism, either—certainly not those who write long textbooks where short ones would serve better, who use big words and obscure expressions where a little more toil or humility would find short words to do a better job.

To some extent an educational book may be viewed as an automatic machine for the mass production of certain ideas and skills among large groups of people. Yet the book can never be a complete instrument of education, for it cannot spare the student the need to work his own problems, do his own thinking, and drill himself for practical mastery of its contents.

Because the book is a product of, as well as an instrument of, mass production, it is the least costly of all educational tools per unit of work accomplished. The man who really masters a carefully selected, three-dollar technical book will likely devote $100 worth of time and effort to the job of mastering it, and thereby will acquire skill with a market value of a thousand dollars. In this matter of books, a little side remark may be in order. After many discouraging experiences with long books, I have acquired almost a mania for short ones.

All of us, when we leave school, plan "some day" to continue or to take up the study of literature, history, astronomy, differential equations, or what have you. Most of us never will—not to our dying day. Why is it? I think I know. As college graduates, we feel that we should tackle the selected subject in an ample scholarly volume. It's a great mistake. Unless you are a very unusual person, take my advice; find yourself a little book, a primer—probably something written for seventh-grade students, or immigrants, or maybe even morons. Incidentally such books often are written with more care and skill than those directed at more advanced students. Study your little book from the first page to the last, and master everything in it. Almost invariably you will discover something you never knew before, enough to pay you for your time and investment. Then, if you still have any ambition left, go through the subject again with a larger book—again, thoroughly. That formula, I am certain, is the only cure for the average graduate's failure to continue profitable home study once he gets beyond range of the schoolmaster's lash.

I believe in lectures only slightly. I believe in books a lot more. Yet, I would consider any educational system defective in which the student spent as much as 50 per cent of his learning time in lectures and book reading combined. This means that he should spend more than 50 per cent of his time in solving problems, drawing pictures, working in shops and laboratories—doing almost anything except reading or listening to lectures.

This question of doing, as opposed to listening and reading, leads directly to the question of practical shop experience for engineers. Certain of the engineering schools have no student shops. Others are reducing the time spent in college shopwork. Some educators are saying that college shopwork doesn't fill the bill. Perhaps they are right; I can't argue the point because all my own shop experiences was obtained in commercial machine shops in summer vacations.

Where the shop experience can best be had is a proper subject for discussion, but on one point there can be no disagreement—the engineer who graduates from engineering school without a substantial shop background obtained somewhere and somehow definitely is handicapped. Creative design and engineering management rest as much on trained intuitions as on academic knowledge. Only work with one's own hands in an actual shop can give one the right "feel" of metals, machines, working people, and working methods.

Some may ask whether this experience cannot be delayed until after graduation. I say no. Why deny the student the early practical background that will help him evaluate his college studies? Why inflict on the young graduate the mental sufferings of a degree-labeled complete tenderfoot in industry? Why make things harder for the young graduate by setting up the degree as a social barrier before he has had a chance to know workmen from their own level? Why ask an older man to learn slowly what he could have learned better when young?

So far I have expounded my personal views. Let's

consider what others say. I asked a number of leading engineering educators, "Is this war teaching us something about the art of learning and the art of teaching—something we can apply after the war, to the end that our people may live more happily and more effectively?" The complete answers are extremely interesting, but space permits only a brief summary of the high spots.

One who asks to be identified only as an unconventional, iconoclastical, metropolitan dean, says that many engineering colleges have been brought in touch for the first time with young men in engineering positions in industry through the engineering, science, and management war training (ESMWT) courses. In industrial background and sincerity and appetite for knowledge these night students from industry far outshine their day brothers, says this dean. He foresees a great postwar extension of night degree courses and an elimination of the traditional snobbish faculty attitude toward such courses.

In Rochester, N. Y., is one of America's most successful institutions of practical education—the 114-year-old Rochester Athenaeum and Mechanics Institute, with a present enrollment of 4,500. President Mark Ellington of the Institute writes that traditional education involves too much lecturing and book work and not enough doing. The reasons, he says, are custom plus the higher cost of doing the job right. Because of the war, millions of men in and out of the armed services have been given practical, intensive instruction. Never again will they be satisfied with traditional procedures.

From Washington writes M. J. Kane, assistant director, training within industry, War Manpower Commission: "There is no need to seek further for new ideas in connection with training. The imperative thing is to get action and to do some of the things which we have known for many years, but have only talked about. We now find that the need is for specific direct help to individuals to meet their particular problems. Such things as job instruction, job planning, and job-relation training have been reduced successfully to short ten-hour units. When given to hundreds of thousands of supervisors, these will affect favorably the entire fabric of all industries."

Dean A. A. Potter of Purdue University, Lafayette, Ind., who has contributed greatly to the adjustment of engineering schools to the country's wartime needs, says it is certain that our educational institutions of higher learning will not be taken over by government. From wartime activities we are learning to compress information in undergraduate curricula. For the future he expects less specialization in the undergraduate curriculum, but increased emphasis on new types of courses, particularly in the field of electronics. Dean Potter foresees increasing importance of the technical-institute type of education, giving practical education without degrees.

Professor Theodore Baumeister, head of the mechanical engineering department at Columbia University, New York, N. Y., asks: "Has not the experience of the last few years demonstrated that the previously prevalent and traditional forms of education are seriously wanting?" In particular, he questions the value of the Bachelor of Arts degree obtained with no study of true science, technology, physics, chemistry, biology, and similar courses. Looking to the future, he suggests that the heavier requirements on engineers may necessitate more graduate work.

R. L. Goetzenberger, vice-president of Minneapolis-Honeywell Regulator Company believes that universities and local industries will be forced to co-operate in the training of efficient industrial managers. To insure success of this work he recommends that the colleges virtually draft capable industrial administrators in the vicinity to serve as part-time consultants and practical lecturers.

SUMMARY

In conclusion, let me sum up my present personal views on education:

1. The classical tradition, long on the defensive, will continue to lose ground.

2. Vocational competency and good citizenship are the noblest aims of education.

3. Some of the highest cultural values are a natural by-product of sound vocational education.

4. Certain nonvocational studies that pay high dividends in human satisfaction (music, art, literature, modern languages, and the like) will be accepted eagerly everywhere, whereas those humanities that cannot stand on their own feet will "get the gate."

5. The explosions of global war will shake American educational institutions to their foundations, and will force revaluation all along the line.

6. The quality of teaching and learning must improve, with more attention to thoroughness and less to extent of coverage.

7. "Lecture-course" methods of teaching exact sciences and practical skills should be discredited as sloppy, superficial, unworthy of respect.

8. This does not imply that lecture courses are unsuitable for the teaching of such intangibles as ethics, philosophy, and politics.

9. Lectures also have a definite place in the teaching of the rigorous scientific and practical disciplines, but only when paired with far more time devoted to work and expression by the student.

10. There will be growing appreciation of the school book, or home-study book that is concise, simple, and practical.

11. More and more adults will study this or that subject for self-advancement or pleasure, using skillfully prepared short books and skillfully taught, short, nondegree courses in a great variety of institutions.

12. It will become more obvious that an education obtained by passive absorption, without auxiliary use of the muscles, is rarely worthy of the name. He who would study with profit must talk, write, draw, or handle tools—somehow must constantly put into action what he learns. Otherwise, he won't learn.

13. The power of the right education to create wealth, happiness, and domestic and international tranquillity is almost beyond belief. Nothing in the world is more important than doing this job right. Let's get to it!

Synthetic Rubber in the Making

Figure 1. These 30,000-gallon storage tanks contain basic butadiene and styrene

Butadiene, a gas composed of hydrogen and carbon, and styrene, a liquid derivative of coal tar and petroleum, are the principal constituents of buna-S synthetic rubber. The Institute (W. Va.) Plant, operated for the government by the United States Rubber Company, has nine of these tanks for butadiene and three for styrene. This storage capacity is sufficient to operate the plant for three days, and will produce enough rubber to make 190,000 passenger-car tires

Figure 2. Apparatus used to remove the chemical inhibitor which must be added to butadiene in storage to prevent premature polymerization

Figure 3. Transfer pump house, where the pumps which transfer the raw materials from the storage tanks to reactor areas are located

Three parts of butadiene to one part of styrene, together with special chemicals, are moved through pumps and pipe lines (Figure 3) to large glass-lined reactor vessels (Figure 4), where the mixture is agitated and polymerization takes place

Figure 4. Top view of some of the plant's 72 reactors, which can produce 90,000 long tons of synthetic rubber annually

Figure 5. Blowdown tanks, into which the polymerized mixture is blown down to arrest the reaction

Unreacted butadiene and styrene are recovered here by vacuum and steam for return to the process. At this stage the mixture forms a basic latex similar to natural rubber

Figure 6. The synthetic rubber latex is batched and blended in the plant's 12 30,000-gallon storage tanks

Blending of the latex assures uniformity of the product. The rubber content of the latex is then coagulated by acid and separated out in the form of flocs or crumbs

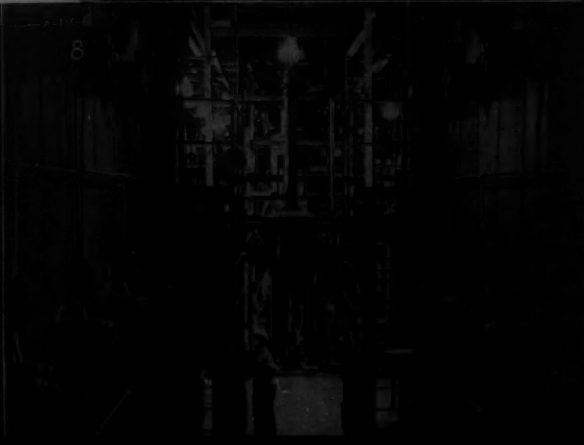
Figure 7. Flocs of synthetic rubber being washed to remove the excess chemicals used in previous stages

Figure 8. Steam driers, which remove all water from the soggy rubber crumbs

The crumbs of rubber are passed back and forth three times on a slowly moving belt of metal through these driers. At full operation, 12 of these driers will evaporate 160 tons of water a day

Figure 9. Loaf of baled rubber—the final stage in the manufacturing process—ready for production purposes

Bales are packed into treated cartons to prevent sticking; 9,000 such loaves are produced daily at this plant



INSTITUTE ACTIVITIES

Wartime Power-System Problems Feature Roanoke Technical Sessions

In accordance with the wartime policies adopted last year by the AIEE board of directors, heavy emphasis was placed on problems related to the war at the AIEE Southern District technical meeting held November 16–18, 1943, at Roanoke, Va. In fact, almost every single item on the program was related either directly or indirectly to problems imposed by the war.

As previously scheduled, the technical program comprised four sessions at which 13 papers were presented. Wartime operating problems of the power companies in the Southern District territory predominated at these sessions. An opening session, two evening sessions (one of which was a dinner meeting), and a student conference rounded out the program. In addition, the executive committee of the Southern District held a luncheon meeting on the opening day.

Total registration at the three-day affair was 220, which was especially good, considering that the 147 members of the host Section are distributed throughout the state of Virginia, and in the city of Roanoke itself there are only six members. Attendance at all sessions was excellent.

The Southern District of AIEE is comprised of 11 Sections and 18 Student Branches in the states of Florida, Alabama, Mississippi, Louisiana, Georgia, Kentucky, Tennessee, South Carolina, North Carolina, and Virginia. This was the first District meeting to be held in the state of Virginia.

President Funk Spoke at Opening Session

The three-day meeting was officially opened by General Chairman A. P. Gompf (A '27) Chesapeake and Potomac Telephone Company of Virginia, Richmond, who presided at the opening session. Mayor Leo F. Henebry of the city of Roanoke extended the official welcome to those attending the meeting, declaring that the electrical industry contributes more to our daily lives than any other industry. AIEE Vice-President C. W. Ricker of New Orleans, representing the Southern District, responded and then spoke briefly on certain aspects of the meeting.

Principal address of the session was delivered by AIEE President Nevin E. Funk. He predicted a new era in electricity after the war and declared that we have as yet only scratched the surface of absolute scientific knowledge.

In response to those who advocated discontinuing national and District AIEE meetings during the war in order to save transportation, Doctor Funk said that these meetings are needed now more than ever. The majority of Institute members are now in new activities and therefore need the exchange of ideas which these meetings make possible. He also reported that a joint intersociety committee has been organized to study postwar problems.

Doctor Funk lamented the fact that the engineering profession as a whole has no national voice as have the professions of law and medicine. A joint intersociety committee is now studying this problem. Joint meetings which are becoming increasingly popular among local societies and local organizations of national societies represent an important step forward in the direction of greater solidarity within the profession, he concluded.

Technical Sessions

Wartime operating problems of power companies in the southeastern states and their solution formed the general subject matter of the four technical sessions of the recent AIEE Southern District meeting in Roanoke, Va. Specific subjects discussed included: the application of capacitors; design and operation of governors and tie-line control; new generating equipment recently installed to handle wartime increases in load. Other subjects included boatbuilding, gas-filled cable, new materials now being developed, and the technical training programs of the United States Armed Forces. Attendance at all sessions was exceptionally good.

Presiding at the sessions were: Herman B. Wolf (M '37) Duke Power Company, Charlotte, N. C.; Stanley Warth (M '36) Southern Bell Telephone and Telegraph Company, Jacksonville, Fla.; J. Elmer Housley (M '39) Aluminum Company of America, Alcoa, Tenn.; and H. E. Wilson (M '32) Carolina Power and Light Company, Raleigh, N. C. [in place of A. S. Hoefflin (M '40) Louisville Gas and Electric Company, Louisville, Ky., who was unable to attend].

Attending the Roanoke meeting were N. E. Funk, president of AIEE, who spoke at the opening session and E. W. O'Brien, vice-chairman of the committee on Student Branches, who presided at one of the evening sessions

APPLICATION OF CAPACITORS

Three papers on capacitor applications comprised the scheduled presentations at one session. Use of these units to improve voltage regulation of heavily loaded circuits, to supply kilovars at the load and thus avoid or postpone the necessity of installing new generating equipment, and to meet special conditions was discussed.

A study of the application of capacitors on a system-wide basis, made by means of the network analyzer, was reported in a paper, "The Effect of Kilovar Supply on the Design of Systems for Load Growth," by T. W. Schroeder (A '37), J. W. Butler (M '38), and N. H. Meyers (A '41), of the General Electric Company, Schenectady, N. Y. Mr. Schroeder presented the paper. Even though a conservative system was chosen for analysis, the results showed that the supply of kilovars by capacitors installed at or near the load is advantageous, both economically and otherwise. This paper has been approved for re-presentation at the AIEE 1944 winter technical meeting and is scheduled for inclusion in the *Transactions* section of the February 1944 *Electrical Engineering*.

A 13,500-kva bank of static capacitors installed at the Newport News substation of the Virginia Public Service Company was described in a paper by V. R. Parrack (M '31) of that company and E. L. Harder (M '41) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. The paper was presented by Mr. Parrack. Wartime increases in load in the Newport News area were such that, although existing generating and transmission facilities could handle the kilowatt requirements, they could not carry both the required kilowatts and kilovars. Therefore, it was decided to supply the kilovars at the substation. Advantages of faster delivery, use of less critical materials, lower cost, greater flexibility, and lower losses led to the selection of capacitors rather than a synchronous condenser. Also the capacitors had the added advantage of not increasing the interrupting duty of the station circuit breakers. The installation comprises 900 15-kva pole-type capacitor units arranged in five sections and switched in blocks. Operating experience was reported to be quite satisfactory.

Capacitor applications in pumping stations of the Big-Inch and Plantation oil pipe lines were described by M. A. Hyde, Jr. (A '27) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Although the substations along these lines are very similar, their power

Among those at the Roanoke meeting were: C. W. Ricker, vice-president, Southern District; A. P. Gompf, chairman, general meeting committee; E. S. Fitz, vice-chairman, general meeting committee; F. E. Johnson, Jr., secretary, Southern District; and T. H. Mawson and F. H. Sittloh of Birmingham, Ala.

services vary widely. As a result, capacitors were installed at several substations, principally to improve the running conditions of the pump motors. Special conditions at one substation, however, made it desirable to install two capacitor groups, one for continuous duty and one for intermittent duty during motor-starting periods.

GOVERNORS AND TIE-LINE CONTROL

The close interrelationship between prime-mover speed governors and tie-line control equipment was emphasized in three papers presented at one session, two on governors and one on tie-line control.

C. L. Avery, Woodward Governor Company, Rockford, Ill., outlined the design and operating characteristics of modern hydraulic governors for hydroelectric units and pointed out that the governing problem is a phase of the larger problem of system stability. Modern governing systems have an over-all sensitivity of $^1/_{20}$ of one per cent and a speed regulation capable of adjustment from zero to five per cent, as required. Mr. Avery also described a special type of frequency recorder developed to check the performance of governors, presented test results demonstrating its usefulness, and discussed performance of governors when operating in conjunction with automatic frequency and load control.

A second paper on hydroelectric-unit governors, presented by J. F. Roberts, of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., outlined the seven major functions of governors, only two of which require extreme accuracy or sensitivity: instantaneous frequency control and tie-line loading. Modern governors, Mr. Roberts said, show a sensitivity of from $^1/_{25}$ to $^1/_{100}$ of one per cent. Proper care and maintenance are required to retain this sensitivity. Mr. Roberts also drew some comparisons between the problems of governing steam and hydroelectric units.

Design and application of tie-line load-control equipment were discussed by S. B. Morehouse (A '35) Leeds and Northrup Company, Philadelphia, Pa. He stated that the co-ordination of tie-line control equipment with governors is necessary for best tie-line operation. The tie-line control causes the governors to communicate the varying requirements of the load to the generators. Tie-line control equipment is co-ordinating load distribution throughout load areas, Mr. Morehouse said in outlining the application and operation practices in large interconnected systems. Simplification is desirable within limits, but the equipment must be flexible enough to meet the requirements.

Discussion of these papers revealed that the point of view of the power-system operators differs somewhat from that of the equipment manufacturers. Although there appeared to be general agreement as to the need for proper co-ordination of tie-line control and the governors, there was some difference of opinion as to the relative importance of the governors. It was pointed out that there must be proper co-ordination between the tie-line control and the system relays. The belief was expressed that, since frequency and load control are electrical problems, the governing might also be appropriately accomplished electrically rather than mechanically as at present. One operator stated that most of the governors on a system do not contribute to frequency control, but serve mainly as "watch dogs" to function in case the generating units become isolated from the rest of the system. Another operator took the opposite view that modern governors make possible the present widespread interconnected operation. Opinion seemed to be unanimous as to the need for careful maintenance of equipment.

NEW GENERATING EQUIPMENT

Two new generating stations and new equipment at two other stations were described in three papers. C. C. Dodge (A '20) of the Stone and Webster Engineering Corporation, Boston, Mass., discussed the new Chesterfield station near Richmond, Va., now under construction. The keynote of design of this station was the conservation of critical materials, featuring such wartime practices as the use of wood in place of steel in many instances and the use of corrugated asbestos board for outside wall coverings. In spite of many departures from conventional practice, the designers believe it will prove a reliable source of power. The station will house one 50,000-kw unit supplied from a single coal-fired boiler capable of furnishing 525,000 pounds of steam per hour at a pressure of 875 pounds per square inch and 900 degrees Fahrenheit.

The other new station featured was the Paddy's Run station of the Louisville (Ky.) Gas and Electric Company, described by M. S. Winstandley (A '29) of that company. Unlike the Chesterfield station, this station was designed and the materials purchased for it before the war. The design therefore is conventional. Although intended for an ultimate capacity of 300,000 kw, it now contains only two 25,000-kw 3,600-rpm hydrogen-cooled units. Steam conditions are 650 pounds per square inch and 900 degrees Fahrenheit. Generation began in July 1942. Its output is being absorbed largely by nearby war industries.

Wartime additions now under construction in two stations of the Virginia Public Service Company were described by G. M. Tatum (A '40) of that company, in a paper prepared jointly by himself and R. H. Boas of Gilbert Associates, Inc. A new 15,000-kw steam unit to operate at 625 pounds per square inch and 850 degrees Fahrenheit is being installed in the company's Alexandria station. At the Hampton station, a 6,000-kw topping unit to operate at 900 pounds per square inch and 870 degrees Fahrenheit is being added; it will exhaust into the station's present low-pressure system at 210 pounds per square inch.

In the discussion period following these three papers, Philip Sporn (F '30) American Gas and Electric Corporation, New York, N. Y., described wartime additions that have been made to generating and transmission facilities of the American Gas and Electric Company central interconnected system. The aggregate wartime increase in system capacity is greater than that of any other privately owned company in the United States, Mr. Sporn declared.

OTHER SUBJECTS DISCUSSED

"Influence of New Materials on Design" was the subject of a talk by R. C. Bergvall

(M '41) Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. New materials and methods have given us greatly improved equipments of many types, although the basic principles may have remained the same, he said. Electrical manufacturers use a wider range of raw materials than most other manufacturers; and, with the war restricting the supply of many of these materials, the industry has been conducting an intensive search for new materials and new methods of using materials. Mr. Bergvall described some of the advances already made in this direction and exhibited samples. He related how research in grain orientation in core iron has resulted in smaller transformers. He described some of the uses of the mass spectrometer and predicted new uses for this device. Speaking of electronic applications in industry, Mr. Bergvall discussed the expanding use of induction and dielectric heating at high frequencies and predicted that new more rugged tubes will extend the use of these devices in industry. High-temperature alloys that can be used in developing gas turbines are being formulated. He expressed the opinion, however, that small gas turbines for stand-by use are likely to be developed first, these units having relatively short life because of the high temperatures involved.

Wartime technical training was reviewed by W. S. Rodman (F '28) University of Virginia, Charlottesville, who traced the effects of the war on technical training from pre-Pearl-Harbor days to the present and discussed some of the difficulties faced by educators and students in the latest Army and Navy programs. For the latest Army specialized training program (ASTP) and the Navy college training program (NCTP), aimed to give technical training to men of officer caliber, some 30,000 candidates have been obtained as a result of competitive examinations among high-school graduates and 5,000 candidates from men already in the services. Many more candidates are needed. Refresher courses have been organized for those who have been away from school an appreciable time. Dean Rodman said that the courses are so intensive in nature that they are extremely difficult for the institutions to organize and teach; furthermore, even exceptional students can maintain satisfactory records only with the greatest difficulty. He expressed the hope that the program would be altered to alleviate some of these problems. Dean Rodman mentioned also, that many women are being given special courses to fit them for specialized duties in industry.

The construction and operating characteristics of a 38-kv low-pressure gas-filled cable for the underground section of a new feeder of the Virginia Electric and Power Company were described in a paper by W. A. Del Mar (F '20) Phelps Dodge Copper Products Corporation, Yonkers, N. Y., and A. F. Gambitta (A '26) Phelps Dodge Copper Products Corporation, New York, N. Y. This cable was selected after much careful thought to meet the fast expanding wartime load in the Hampton Roads area. The cable contains three 600,000-circular-mil sector-type impregnated-paper-insulated conductors and three 0.375-inch copper tubes for distributing the gas. Each insulated conductor is wound with a perforated copper shielding tape. Diameter over the lead sheath is 3.25 inches. One of the copper tubes is solid and continuous throughout the entire length of the cable, being tapped to the cable interior at the joints. The other two tubes are helical and distribute the gas between joints. Gas pressure within the cable is maintained between 10 and 15 pounds per square inch. A special relay sounds an alarm if pressure becomes too high or too low. After the paper was presented, W. F. Nimmo (M '35) of the power company, showed a motion picture depicting some of the more interesting installation steps.

War flavor of a somewhat different type was injected into the program by Milton L. Levy of the Higgins Industries, Inc., New Orleans, La., who described the construction of small naval vessels of specialized types, such as motor-torpedo boats and various types of craft for landing men and equipment. His talk was supplemented by motion pictures showing the testing of these craft.

Evening Sessions

Spokesmen of both the Army and the Navy were on the program of the dinner meeting Tuesday evening, November 16. J. H. Berry (M '31) Virginia Electric and Power Company, Norfolk, Va., presided.

Lieutenant Colonel M. P. Chadwick of the Signal Corps related some of his experiences during the Japanese sneak attack on Pearl Harbor and later, on Guadalcanal Island. He explained how radio and wire communication was used in the latter campaign. Colonel Chadwick reported that the equipment functioned well, but some trouble was experienced with wire lines. All component parts of radio must be waterproofed for use in jungle warfare, he said, and the units must be rugged enough for transport by jeep over rough terrain. Gasoline-engine-driven generators furnish the required electric power. Japanese radio equipment captured in that engagement had been manufactured in 1937–38.

Captain H. G. Rickover of the Bureau of Ships described some of the latest electrical applications on modern warships of the United States Navy and related how the radically different conditions encountered in the present war, as compared with the last war, have brought about many changes in practices and in equipment design. His talk was supplemented by slides showing electrical equipment that had been submerged in ships damaged at Pearl Harbor.

Feature address at the second evening session held Wednesday, November 17, was by E. H. Alexander of the General Electric Company, Schenectady, N. Y., who spoke on "Electronics in Industry." He said that electronics was being misrepresented to the general public in popular magazine articles and advertisements. Pointing out that industrial electronic devices have been in successful use for more than 20 years, he declared that we are not on the verge of an electronic age—we are already in it. Mr. Alexander then proceeded to discuss four different types of equipment, for (1) measurement, (2) power conversion, (3) heating, and (4) control purposes. His talk was supplemented with slides showing typical equipment.

Following the feature address, two motion pictures were shown depicting, respectively, in popular language, the inner workings of frequency-modulation (*FM*) radio and television. Eugene W. O'Brien (M '37) managing director and editor, *Southern Power and Industry*, Atlanta, Ga., presided.

Student Program

The main event of the Student Branch conference Wednesday at 2:00 p.m. was the presentation of three technical papers on a competitive basis by Enrolled Students. The papers presented were:

1. X Rays; H. L. Fanning and H. Williams, University of South Carolina.

2. Electronics and Torque Measurements; R. E. LeBlanc III and E. G. Holmes, Tulane University

3. Electronic Development and Applications; B. C. Carr, Jr., Virginia Polytechnic Institute.

The prize was awarded to LeBlanc and Holmes.

E. W. O'Brien (M '37) vice-chairman of AIEE national committee on Student Branches, H. H. Henline, national secretary, and C. W. Ricker, District Vice-President, addressed the meeting informally. W. O. Leffell (A '37) counselor of the University of Tennessee Branch, Knoxville, was elected new District chairman of student activities and District counselor delegate to the 1944 annual meeting. It was decided to hold the next student conference at the University of Tennessee in April 1945. Claudius Lee (M '13) professor of electrical engineering, Virginia Polytechnic Institute, presided.

District Executive Meeting

The Southern District executive committee held its regular annual business session Tuesday, November 16, in Roanoke, Va. Attendance which totaled 24 members showed representatives from 10 of the 11 Sections in the District. Among those present were District Vice-President C. W. Ricker, District Secretary F. E. Johnson, Jr. AIEE President Nevin E. Funk, National Secretary H. H. Henline, and Past Vice-Presidents Mark Eldredge, J. Elmer Housley, and W. S. Rodman were present as guests.

J. Elmer Housley was elected representative to serve on the national nominating

Analysis of Registration at Roanoke

Classification	Virginia Section	District 4*	Other Districts	Total
Members	40	60	44	144
Enrolled Students	4	3	1	8
Men guests	34	10	14	58
Women guests	4	2	4	10
Totals	82	75	63	220

* Outside Virginia Section.

committee, and J. R. Smith was chosen alternate. Definite plans were made to hold the next Southern District meeting in the fall of 1945, probably in South Carolina.

A definite trend toward greater co-operation among the different branches of engineering through joint meetings in the field was reported. Most Sections are either sponsoring such meetings in co-operation with local engineering clubs or societies, or jointly with local groups of other national societies.

Committees

General committees and subcommittees which planned the meeting were:

General Committee: A. P. Gompf, *chairman;* E. S. Fitz, *vice-chairman;* C. W. Ricker, *AIEE vice-president representing the Southern District;* F. E. Johnson, Jr., *secretary,* Southern District; F. W. Chapman, E. R. Coulbourn, C. E. Creecy, R. M. Ferrill, J. F. Fomick, R. C. Fuller, C. P. Knost, J. E. Mellett, J. J. Strickland, C. F. Titus, and L. G. Weiser.

Hotels and Transportation: W. I. Whitefield, *chairman;* A. R. Hines and J. L. White.

Publicity and Attendance: Cecil Gray, *chairman;* A. F. Forbes, W. A. Murray, and W. F. Nimmo.

Technical Papers: R. C. Bailey, *chairman;* C. P. Knost, A. W. Lee, Jr., and H. E. Wilson.

Student Activities: Claudius Lee, *chairman;* Brinkley Barnett, W. M. Bauer, J. A. Cronvich, H. B. Duling, W. W. Hill, J. S. Jamison, L. M. Keever, W. O. Leffell, N. M. McCorkle, Otto Meier, Jr., J. S. Miller, Jr., W. J. Miller, M. G. Northrop, A. K. Ramsey, S. R. Schealer, E. F. Smith, and F. T. Tingley.

Finance: C. L. Crosby, *chairman.*

NATIONAL • • • •

Board of Directors Meets

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., October 27, 1943.

Upon recommendation of the Standards committee, the board approved for publication Proposed Standard 3, Guiding Principles for the Selection of Reference Values, developed by Standards co-ordinating committee 1, and approved the appointment of D. M. Petty as AIEE representative on sectional committee C35 on railway motors, to succeed E. L. Moreland, resigned.

Authorization was given for holding a North Eastern District technical meeting in Boston, during the last two weeks in April 1944, and a Pacific Coast technical meeting in Los Angeles, August 29 to September 1, 1944, inclusive.

Pursuant to actions of the board of directors on October 23, 1942, and June 24, 1943, the following amendments to the bylaws, submitted by the committee on constitution and bylaws, were adopted:

Section 65. "Committee on electronics" added to the list of technical committees.

Section 68. "The Chairman of the Standards committee" added to the list of ex-officio members of the technical program committee.

Section 80. In the list of states forming the various geographical Districts, the States of North Dakota and South Dakota transferred from the listing under District 6 to the listing under District 5.

In accordance with section 22 of the bylaws, five members of the board of directors were selected to serve on the national nominating committee, as follows: M. S. Coover, C. M. Laffoon, T. G. LeClair, E. W. Schilling, W. Ralph Smith. Two alternates were designated, namely, K. B. McEachron and H. S. Osborne.

Upon nomination of the committee on engineering schools of the Engineers Council for Professional Development, the board approved the appointment of V. P. Hessler as an AIEE representative on the delegatory committee for region V, to succeed A. C. Lanier, deceased.

Upon recommendation of a special committee appointed to consider the proposal, the board accepted an invitation for the Institute to become a contributing sponsor of the recently organized Radio Technical Planning Board, and designated George T. Harness as the AIEE representative thereon. The appointment of an alternate was referred to the president.

A progress report was made by the Institute representative, R. G. Warner, on the joint committee, appointed by the joint conference committee of presidents and secretaries of engineering societies, to study the activities of Student Branches under wartime conditions. Decisions have been made to endeavor to enlist the co-operation of the Student Branches of the various societies, through combined meetings, or simultaneous meetings, and to solicit the support of the Army and Navy authorities for Student Branch activities insofar as the Army and Navy trainees are concerned.

Upon recommendation of the chairman of the AIEE committee on Student Branches, the board took action definitely establishing the eligibility for Student enrollment in the Institute of the students in the Army and Navy programs.

An invitation to participate in the commemoration of the 50th anniversary of the American Society of Heating and Ventilating Engineers, in New York, January 31 to February 2, 1944, was accepted, and the president was authorized to act as the Institute's representative on this occasion, or to appoint someone else to attend.

Actions of the executive committee as of September 30, 1943, were reported and confirmed, as follows: 8 applicants transferred and 1 elected to the grade of Fellow; 37 applicants transferred and 23 elected to the grade of Member; 119 applicants elected to the grade of Associate; 421 Students enrolled. Recommendations adopted by the board of examiners at meetings on September 23 and 30 and October 21, 1943, were reported and approved. Upon recommendation of the board of examiners, the following actions were taken: 15 applicants were elected to the grade of Member; 73 applicants were elected to the grade of Associate; 249 Students were enrolled.

The finance committee reported a total income for the year which ended September 30, 1943, of $407,432, and a total expenditure of $312,978. The budget for that year amounted to $352,000. A budget for the appropriation year beginning October 1, 1943, amounting to $370,000, submitted by the finance committee, was adopted.

Present:

President—Nevin E. Funk, Philadelphia, Pa.

Past President—H. S. Osborne, New York, N. Y.

Vice-presidents—A. G. Dewars, Minneapolis, Minn.; J. M. Gaylord, Los Angeles, Calif.; W. J. Gilson, Toronto, Ont.; C. R. Jones, New York, N. Y.; K. B. McEachron, Pittsfield, Mass.; C. W. Ricker, New Orleans, La.; E. W. Schilling, Bozeman, Mont.

Directors—T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair, Chicago, Ill.; C. W. Mier, Dallas, Tex.; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; W. Ralph Smith, Newark, N. J.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter, New York, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

Minutes of the meeting of the board of directors held August 4, 1943, were approved.

Other matters were discussed, reference to which may be found in this or future issues of *Electrical Engineering.*

Winter Technical Meeting to Feature War and Postwar Topics

Arrangements are in progress for the winter technical meeting, which will be held in New York, N. Y., January 24–28, 1944, with headquarters in the Engineering Societies Building. The Edison Medal will be presented during this meeting.

A number of technical sessions and technical conferences will be held to present subjects which are of aid to the war effort and which also will be of value in the postwar period. Continuing the co-operative work of co-ordinating meeting schedules the Institute of Radio Engineers' winter technical meeting will be held concurrently on January 28 and 29. The programs are being arranged so as to afford three days of continuous interest for members concerned with radio and communication work.

Thursday evening, January 27, a joint AIEE–IRE session is planned with Major General Roger B. Colton, chief, engineering and technical service, Signal Corps, United States Army, the principal speaker. Major General Colton will discuss enemy communication equipment.

SMOKER

In order that those attending the winter technical meeting may have an opportunity to get together with their friends under conditions where all may relax and pass a

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 24–28, 1944

North Eastern District Meeting
Boston, Mass., April 1944

Summer Technical Meeting
St. Louis, Mo., June 26–30, 1944

thoroughly enjoyable evening it has been decided this year to have a smoker, Tuesday evening, January 25, at the Hotel Commodore. Insofar as possible, all conditions surrounding the affairs of previous years will be provided. Tickets, including dinner and show, will be five dollars per person. Tables for ten can be reserved by advance payment. Checks should be made out to "Special Account, National Secretary, AIEE."

THEATER TICKETS

Because of the difficulty in obtaining theater tickets under present conditions, only a limited number of such tickets will be made available for Thursday evening, January 27. In selling these tickets preference will be given to out-of-town members. Members desiring tickets for specific performances may write to Institute headquarters, enclosing checks made out to "Special Account, National Secretary, AIEE," and every effort will be made to secure seats. If alternative shows or dates are acceptable, these should also be given.

COMMITTEE

The personnel of the 1944 winter technical meeting committee, which is making the arrangements, is as follows:

J. F. Fairman, *chairman;* W. J. Barrett, F. A. Cowan, J. L. Callahan, M. D. Hooven, C. R. Jones, R. A. Jones, F. V. Magalhaes, C. S. Purnell.

Contents of December 1943 Supplement Announced

Technical papers to supplement those published in the monthly Transactions sections of *Electrical Engineering* for July through December will appear in the December 1943 "Supplement to Electrical Engineering—Transactions Section." This supplement will contain 12 papers, their discussions, and the discussions of technical papers published in the July–December monthly sections. Publication of this supplement completes the publication of papers and discussions presented at the 1943 AIEE North Eastern District meeting in Pittsfield, Mass., the 1943 AIEE summer technical meeting in Cleveland, Ohio, and the 1943 AIEE Pacific Coast meeting in Salt Lake City, Utah.

Copies of the supplement will be available within a few weeks and will be mailed to those who entered advance orders. Others may obtain copies at 50 cents each from the AIEE order department, 33 West 39th Street, New York 18, N. Y.

Papers appearing in the December 1943 Supplement, abstracts of which have been published in *Electrical Engineering* in advance of the meetings, are:

43-66—The Frequencies of Natural Power Oscillations in Interconnected Generating and Distributing Systems; *Reinhold Rüdenberg (M '38).* Abstracted in April 1943 issue, page 172.

43-67—The Sorocabana Railway Electrification; *Dorval Maylaert.* Abstracted in April 1943 issue, page 172.

43-101—Interim Report on Characteristics and Performances of Conductors for Supervisory Control and Telemetering; *AIEE subcommittee on characteristics and performance of conductors for supervisory control and telemetering.* Abstracted in June 1943 issue, page 266.

43-76—Pole-Face Loss in Solid-Rotor Turbine Generators; *W. W. Kuyper (A '34).* Abstracted in June 1943 issue, page 268.

43-77—The Effect of Corona on Coupling Factors Between Ground Wires and Phase Conductors; *G. D. McCann (A '38).* Abstracted in June 1943 issue, page 269.

43-83—Safe Ratings for Overhead Line Conductors; *L. M. Olmsted (M '39).* Abstracted in the June 1943 issue, page 269.

43-80—Application of Carrier to Power Lines; *F. M. Rines (M '41).* Abstracted in the June 1943 issue, page 269.

43-90—Theory of Rectifier—D-C Motor Drive; *E. H. Vedder (M '35), K. P. Puchlowski (A '43).* Abstracted in the June 1943 issue, page 269.

43-137—Turn Ratio of the Capacitor Motor; *T. C. MacFarland (M '32).* Abstracted in the August 1943 issue, page 375.

43-140—Radio-Noise Elimination in All-Metal Aircraft; *Fred Foulon (M '42).* Abstracted in the August 1943 issue, page 374.

43-144—Rectifier Drive for D-C Motors; *K. P. Puchlowski (A '43).* Abstracted in the August 1943 issue, page 375.

43-141—Applications of 720-Cycle Carrier to Power Distribution Circuit; *J. L. Woodworth (A '43).* Abstracted in August 1943 issue, page 275.

Formation of Aircraft Groups Promoted by Sections Committee

The AIEE Sections committee, George W. Bower (M '40) chairman, is promoting the formation of aeronautical technical discussion groups in localities where there is evidence such groups are needed. In addition, the Sections committee, jointly with the membership and technical program committees, is encouraging meetings on this subject in other Sections where the organization of a separate group is not possible because of the lack of available members. Two aircraft discussion groups have already been formed and are functioning, one in the Los Angeles Section, and one in the Philadelphia Section.

Lieutenant Colonel T. B. Holliday (A '41) United States Army Air Corps, Wright Field, Dayton, Ohio, chairman of the air transportation committee, commenting on the drive for aircraft discussion groups, said:

"This activity is worth while and in all probability will be rewarded with a very active interest on the part of Institute members. Most members realize the magnitude of the Air Forces' task in the current war effort and appreciate the success their operations are meeting. A natural result of this is a very intense curiosity regarding the equipment which makes these operations possible.

"This equipment represents some departures from conventional practice insofar as electrical design is concerned, and it is expected to function under conditions which no other type of electrical equipment has ever been expected to meet. Since an airplane can travel from one point to any other point of the world within 60 hours, equipment cannot be designed for local operating conditions, but must be satisfactory in the Arctic cold and in desert heat, must withstand salt-water corrosion and exposure to sand and dust, and must function correctly at 65 degrees below zero and 135 degrees above, at sea level and at altitudes as high as 40,000 feet. At the same time, weight and space must approach a minimum, and adequate reliability must be provided.

"The electrical engineers of the industry have accomplished many miracles in design in meeting these new and difficult requirements. The progress which has been made in this fashion must be of considerable benefit to commercial applications which will follow the war. Therefore, all engineers in the industry will follow the activities of the aviation group with a great deal of interest."

The interest of aircraft electrical engineers in AIEE may be judged from the fact that approximately 150 new members have joined the Los Angeles Section since the formation of the aircraft division. This division offers the aircraft electrical engineer a medium for exchange of ideas and for the discussion of developments and their associated problems. The aircraft division of the Los Angeles Section came into existence March 9, 1943. The first meeting was primarily an organizational affair, held for the purpose of determining the form and frequency of meetings and the most desirable topics for discussion. It was decided to have speakers at future meetings cover a specific subject in a fixed time and then to open the meeting for general discussion. Scheduled meeting dates were not to be rigid, but rather were to be made to suit the occasion. Responsibility for the assembly and presentation of program material were to be delegated to a program committee. It was agreed that the meetings would be dinner meetings whenever possible.

At the first technical meeting, May 26, 1943, Mr. Gagnier of North American Aviation, Inc., discussed the subject, "Aircraft Network Systems and Circuit Protection." The second technical session, July 21, 1943, featured talks on "Protection Devices" by Mr. Stevens of Consolidated-Vultee Aircraft Corporation, and Julian Rogoff of the Burndy Engineering Company. This topic dealt with circuit breakers, fuses, and replaceable links for circuit protection. Many of the problems discussed at this meeting were very similar to those encountered in power-company work. The last meeting of the aircraft division, July 21, 1943, covered the subject, "Electrical Control Equipment for Aircraft." Speakers for the evening were Mr.

Crago and Mr. Bradish of the General Electric Company, and Mr. Lear, Chief Engineer of Lear-Avia, Inc. Demonstrations by both General Electric and Lear-Avia companies of many applications of control systems were featured at the meeting. Attendance at these aircraft meetings has ranged between 200 and 300.

Tentative plans have been made for meetings of the Los Angeles aircraft division to be held January 26, February 23, and March 22, 1944. The January 26 meeting will deal with the subject of "Aircraft Instrumentation" which includes design of installation, installation problems, and consideration of the instruments themselves. G. F. Burnett of the Lockheed Aircraft Corporation will be in charge of this session. February 23 the topic will be "Open-Wiring Design Consideration in Military Aircraft." Fred Foulon (A '30) of the Douglas Aircraft Company, el Segundo Division, will be responsible for this program. The subject for the March 22 meeting will be "Electrical Power Drives for Aircraft Functions." Ernest Seifkin of the Vega Aircraft Company will handle the program for that evening.

The Philadelphia Section has sponsored discussion group meetings in the interest of the aviation industry for the past two years. Through the phenomenal growth of the aviation industry in its area, the Philadelphia Section saw the need for a discussion of aviation subjects and formed the aircraft electrical engineering discussion group. This group has held two meetings to date and has planned three meetings for the 1943–44 season at which technical developments in the aircraft industry were and will be discussed. To obtain greatest benefit for the members, some of the meetings are held jointly with the Franklin Institute. The subject of aircraft has attracted such widespread interest that the board of governors devoted the main meeting, October 11, 1943, to an aircraft program. Lieutenant Colonel T. B. Holliday, chief, electrical branch, equipment laboratory, engineering division of the United States Army Air Corps spoke on the subject, "Development and Trends of Electrical Systems on Military Aircraft." This talk was considered one of the most outstanding talks ever given before the Section.

These aviation activities bring to the Philadelphia and Los Angeles Sections groups extremely enthusiastic on the subject of aviation. Through the enthusiasm shown by the members of these Sections, the tie between AIEE and the aviation industry becomes increasingly stronger.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE winter technical meeting, New York, N. Y., January 24–28, 1944, and will be distributed in advance pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 53 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Air Transportation

44-5—Aircraft Signal Systems; *R. A. Rugge (M '36). 15 cents.* Because the selection of aircraft warning devices has not, in most signal installations, provided the pilot with dependable warnings of dangerous conditions, this paper proposes that aircraft signal devices should be designated and installed in compliance with the pilot's requirements as expressed in three design principles. The paper describes the weaknesses of current signal devices; it recommends signal-light indicators that are bright enough to be seen under direct sunlight; and it illustrates and describes an automatic dimming control that operates as a function of natural light, independent of the pilot's actions.

44-7—Electric Circuits and the Magnetic Compass; *R. C. Burt (F '43), H. R. Beck (Nonmember). 15 cents.* In the airplane large deviations, that is, errors of the magnetic compass may be caused by current-carrying conductors. Such deviations are becoming more important with global flights and the ever-increasing use of steel and electricity. Though space limitations prevent desirable separation of magnetic compass and electric wires, the wiring can be arranged so that deviation is minimized by use of two-wire circuits, divided-conductor single-wire systems, self-compensating placement, and by the use of series-compensating coils. Equations useful in wiring layout are easily developed from the well-known laws of electromagnetism, and such calculations develop limiting tolerable distances for uncompensated wires. This treatment, plus thorough demagnetizing process control, will improve the compass installation greatly, be it direct-reading or remote-indicating, with consequent improvement in navigation and safety.

Education

44-3—Cultural Training of the Engineer; *A. Boyajian (F '26). 15 cents.* Parents, society, and industry, even the armed services, expect engineers to receive a certain amount

Members of the Akron Section are pictured on the steps of the Goodyear Research Laboratory which they visited recently as part of the program of their first fall meeting. After dinner and a motion picture on steam turbines, the meeting concluded with a round-table discussion. The meeting program was arranged by R. F. Snyder (A '40) electrical engineer for the Goodyear Tire and Rubber Company

of cultural training, and for many years the engineering colleges have provided such courses. In this paper the opinion is expressed that the cultural courses have not been so well planned as the technical. The basic cultural needs of the student are: an efficient technique for study, skill in dealing with himself and others, and ability in self-expression, written and oral. These must be not only understood but also converted into habit patterns; and, therefore, their acquisition may not safely be delayed beyond the freshman year. For this objective, the foundation course ought to be practical psychology. The topics to be emphasized are: habit, with appropriate exercises; human motivation; principles of thinking; psychology of attention; and psychology of public speaking and good writing.

Electrical Machinery

44-1—Design of Starting Windings for Split-Phase Motors; *T. C. Lloyd* (*A '31*), *J. H. Karr* (*A '32*). *15 cents.* In the design of split-phase induction motors, the main winding usually is fixed by considerations of the running performance. The starting winding must be so chosen that it results in acceptable values of starting torque and current. Indirect trial-and-error methods which leave the designer in doubt as to whether a readjustment of the winding parameters would not have produced a more effective winding, frequently are used to determine the starting winding. A more direct method, whereby starting winding constants are obtained as functions of main-winding terms, results in simplified calculations yielding the desired performance characteristics, with a quick check on winding effectiveness provided by reference to curve sheets.

44-2—Some Aspects of Electric-Motor Design—Polyphase-Induction-Motor Design to Meet Fixed Specifications; *T. C. Lloyd* (*A '31*). *30 cents.* Many calculation processes whereby the electrical designer can predict the performance of his machine while it is still in the design stage are available. Few data are available for determining the initial dimensions of the proposed design aside from the use of the familiar D^2L formulas for rotating machines. A modern approach to design problems can be defined as one in which the electric and magnetic circuits are solved directly in terms of the performance to be met. A critical examination of the D^2L formula for polyphase induction motors reveals its shortcomings in favor of a process based on design in magnetic circuits of fixed contour which determines at once the windings to meet performance specifications. The point of view, illustrated by polyphase-induction-motor design, is applicable to a wider range of design processes.

44-6—Asymmetrical Loading of Three-Phase Three-Winding Transformer Banks; *P. K. Denisov* (*Nonmember*). *15 cents.* It is accepted Soviet practice to carry three-phase industrial load and single-phase traction load on a single three-phase three-winding transformer. For a given combination of loads it is necessary to determine the proper capacity relationships of the three windings. This paper presents an analysis of the problem by the methods of symmetrical components. The data obtained from this analysis were used in setting up the standards for selection of transformer size for combined three-phase industrial and single-phase traction loading.

44-10—Transformer Magnetizing Inrush Currents and Influence on System Operation; *L. F. Blume* (*F '30*), *G. Camilli* (*F '43*), *S. B. Farnham* (*M '42*), *H. A. Peterson* (*M '41*). *30 cents.* This paper summarizes the results of investigations evaluating the practical significance of power-transformer magnetizing inrush currents. This phenomenon, long recognized, provides a basis for renewed emphasis on questions regarding the effect of inrush currents on system voltages, fuses, and so forth, particularly in view of the present trend toward the use of high-silicon strip steel in the design of power transformers. Miniature system tests, tests on power transformers, and calculations are used as a basis for arriving at definite conclusions. Several corrective means, possibly of value in extreme cases, are discussed with quantitative data included.

Electronics

44-8—Electronically Controlled Dry-Disk Rectifier; *Allen Rosenstein* (*A '41*), *H. N. Barnett* (*Nonmember*). *15 cents.* Selenium-oxide rectifiers are assuming an increasingly important position in the low-voltage d-c power field. The outstanding characteristics of these rectifiers are ruggedness, high efficiency, and maintenance-free operation. The disadvantages are lack of fine voltage variation and only fair voltage regulation under load. This paper describes an electronic control which eliminates these handicaps and makes possible dry-disk rectifiers which possess smoothly variable output voltage that is maintained practically constant under load for any setting. To achieve the regulation, the rectifier voltage is compared against a constant comparison voltage, amplified, and used to shift the phase of the grid voltage of reactor-saturating thyratrons. The saturable reactors, in turn, control the rectifier voltage and compensate properly for voltage changes caused by variations in either load or primary line voltage. Circuit diagrams are shown and performance curves of existing installations given.

44-11—Analysis of Rectifier Circuits; *E. F. Christensen* (*A '39*), *C. H. Willis* (*F '42*), *C. C. Herskind* (*M '40*). *30 cents.* This paper presents a standard procedure for the analysis of rectifier circuits. While the general principles underlying the analysis of rectifier circuits have been covered quite fully in the literature, there is not available a complete analysis giving the essential formulas in a systematic and unified form readily usable by engineers. It is the object of this paper to present such a treatment. The paper describes the methods used in determining the wave forms throughout the rectifier circuit and in deriving the mathematical formulas which apply. While the analysis is made for the widely used delta double-wye circuit, the method is generalized so that it may be applied to all types of rectifier circuits. Rectifier-circuit calculations and presentation of calculated data are facilitated by expressing the various characteristics in terms of the reactance factor. A comprehensive set of characteristic curves expressing the various quantities in terms of reactance factor is included. These curves should prove useful to design, application, and operating engineers.

Industrial Power Applications

44-18—Inverter Action on Reversing of Thyraton Motor Control; *H. L. Palmer* (*A '42*), *H. H. Leigh* (*Nonmember*). *25 cents.* The thyratron rectifier now being applied to the control of d-c motors offers a constant-current decelerating characteristic, similar to and combined with its accelerating characteristic, which can be utilized in reversing and regenerative braking of the motor. By retarding the firing of the thyratrons and reversing the generated voltage of the motor with respect to the tube circuit, the thyratrons can be made to invert the d-c power generated in the motor by the rotational energy of the motor and its connected load, into the a-c system at a constant d-c current. During inversion the d-c current can be controlled by the same means with which it is controlled during rectification. After the motor is decelerated, the circuit can be effectively opened, or it can be shifted to rectifier operation by phase control of the thyratrons to accelerate the motor in the reverse direction.

44-19—A New Electronic Hoist Drive for Cranes; *M. A. Whiting* (*A '07*). *20 cents.* It is generally recognized that for cranes and some other classes of hoists an electric drive is desirable having the inherent characteristic that a heavy load is lowered at a low speed but a light load or the empty hook is lowered at a much higher speed. A system having these characteristics has been developed and successfully applied. This paper explains the theory and design of the system and presents results of tests.

Instruments and Measurements

44-4—An Instrument for the Measurement of Large Alternating Currents; *Walther Richter* (*F '42*). *15 cents.* An arrangement for the measurement and oscillographic recording of large alternating currents is described. The device consists essentially of a flexible air-core transformer, small enough to be easily linked with the low-voltage high-current circuits usually met with in practice, and furnishing

a voltage proportional to the line integral of the magnetic-field intensity around the current to be measured. The theory of the air-core transformer and the fundamental difference between it and the regular current transformer are discussed. It is shown that for currents of high harmonic content the voltage obtained from any air-core transformer is not a direct measure of the current and cannot be used for oscillographic recording. However, by applying the voltage induced in the air-core transformer to an integrating circuit, the resulting voltage can be made very nearly a replica of the original current wave; the auxiliary circuit and amplifier needed to accomplish this are described.

44-9—Polarized Light Servosystem; *T. M. Berry* (*A '43*). *15 cents.* A new servosystem has been developed in which the connecting link between the primary and secondary shafts is polarized light whose plane of polarization rotates with the primary shaft. This makes possible the accurate following of the rotation of the primary shaft without any load being imposed on it. This servosystem has been applied successfully in several electro-mechanical calculating machines.

44-16—A New Differential Analyzer; *H. P. Kuehni* (*M '43*), *H. A. Peterson* (*M '41*). *25 cents.* A new 14-integrator differential analyzer recently has been put into operation by the General Electric Company at Schenectady, N. Y. While this analyzer retains the mechanical interconnection system consistent with established differential-analyzer design practice, significant changes have been made in the integrators themselves. While mechanical torque amplifiers are used in existing analyzers, this analyzer uses a novel Polaroid-light-beam photoelectric follow-up system which has characteristics highly desirable for this purpose. The use of this system has permitted important changes in integrator design.

Power Generation

44-17—Lightning Protection of Rotating Machines; *G. D. McCann* (*A '38*), *E. Beck* (*M '35*), *L. A. Finzi* (*A '40*). *30 cents.* A detailed study of methods for protecting rotating machines connected to exposed transmission lines has been made. This has been based upon the present knowledge of lightning discharge currents. With equivalent circuits used to represent sections of overhead lines and cables, measurements were made of the machine terminal voltages permitted by various circuit conditions when machines are connected directly and through cables or transformers to overhead lines. A study also was made of the surge voltages which can be transferred through cables for various conditions of sheath grounding. Measurements were made of the surge-voltage conditions which can be set up within machine windings under various conditions of machine grounding. This was for the purpose of determining the best method of protection for machines not grounded through sufficiently low impedance to be protected adequately by methods applicable to solidly grounded machines. Specific recommendations are given for improved methods of machine protection under various circuit conditions.

Power Transmission and Distribution

44-12—Steady-State Stability of Synchronous Machines as Affected by Voltage-Regulator Characteristics; *C. Concordia* (*M '37*). *25 cents.* This paper presents a method for calculating directly the gain in steady-state stability with a given voltage regulator and excitation system, and also for predetermining the optimum regulator and excitation-system characteristics to obtain maximum gain in stability for a given synchronous machine or motor-generator set. Results of calculations by the methods developed are given for some typical systems. An important application of the analysis is the case of electric ship propulsion, where the size and weight of the generator and motor are determined in part by steady-state stability requirements.

44-13—Transmission and Relaying Problems on the Fort Peck Project; *Erik Floor* (*Nonmember*), *H. N. Muller* (*M '43*), *S. L. Goldsborough* (*M '43*). *20 cents.* This paper discusses application problems and their solution in connection with power transmission and relaying for the Fort Peck project. Four variations of systems were studied with respect to steady-state and transient stability and the reasons for selecting the particular system used are discussed. An interesting application of a water rheostat as a substitute for a water tower is described. The relaying problems arising from the extreme length of the line are discussed and a modified impedance-relay system is described. Proper ground-relay protection involved the use of three-phase grounding switches at both ends of the line. While the present relaying system does not involve carrier current, a variation of the present system suitable for carrier-current operation is described. Also, other variations in relay characteristics suitable for long lines in general are discussed.

44-15—Regulation of A-C Generators with Suddenly Applied Loads; *E. L. Harder* (*M '41*), *R. C. Cheek* (*A '42*). *30 cents.* Many small fixed and mobile power plants have been built recently for wartime applications. In such applications the major portion of the load frequently consists of one or more induction motors of ratings amounting to an appreciable fraction of the rating of the generator supplying them. The low-power-factor starting currents of these motors may amount to several times rated generator current, producing severe terminal voltage drops during starting periods. Such voltage drops, which may result in the dropping out of motor starters or the pulling out of motors already running because of low terminal voltage, can be reduced considerably by the use of quick-acting regulating and exciting systems. It is essential in the application of such systems to be able to predict maximum generator terminal voltage drops when various amounts of load are applied. In this paper curves are presented that give directly the maximum voltage drops to be expected at the terminals of a-c generators for a wide range of generator, exciter, and load characteristics. Selection of the combinations of characteristics for which curves are presented is based on a study of the effect of each individual factor having a bearing on maximum voltage drops. The voltage-drop curves are based on equations that yield directly the minimum voltage of the generator voltage–time curve following sudden application of load. The derivation of these equations is given in the paper. Test results are presented to support the derivation.

44-14—A Short-Cut Method of Estimating TIF of Power Systems with Rectifier Load; *C. W. Frick* (*A '19*). *20 cents.* A short-cut method is described for estimating the telephone influence factor of power systems with rectifier load, and working curves are given for 60-cycle and 25-cycle systems. The commonly used phase arrangements are covered including 6 and 12 phases as used for the smaller rectifier loads and 24 or more phases as used for the largest rectifier installations. Illustrative examples and comparisons with test results are included. Data pertaining to the effect of a proposed revision of the *TIF* weighting curve on these calculations are given in the appendix.

PERSONAL ....

J. F. O'Connor (M '22) formerly vice-president in charge of the electric operating department, Toledo (Ohio) Edison Company, has been appointed vice-president and assistant general manager of the company. A graduate of the University of Colorado, Mr. O'Connor became associated with the company in 1919 when the Acme Power Company of which he was vice-president and general manager was absorbed by the Toledo Edison Company. In 1922 he was given charge of the general engineering department, and in 1923 made manager of the electric department. From 1929 to 1935 he served as general superintendent and since 1936 he has been vice-president in charge of operations. **H. H. Kerr** (A '17, M '26) formerly superintendent of the electrical department, has been named general superintendent of engineering operation, maintenance, and construction. Mr. Kerr entered the employ of the Edison company in 1929 after 14 years with the Public Service Company of Colorado, Denver. **P. R. Knapp** (A '18, F '38) formerly superintendent of electric distribution and transmission, has been made assistant general superintendent.

Mr. Knapp, a graduate of Worcester Polytechnic Institute, joined the Edison company in 1919. **A. F. Maxwell** (A '31) formerly superintendent of electric distribution, Fremont, Ohio, succeeds Mr. Knapp as superintendent of electric distribution and transmission.

J. T. Frankenberg (A '17, M '13) depreciation studies engineer, New England Telephone Company, Boston, Mass., has retired. Mr. Frankenberg received his mechanical engineering degree from Ohio State University in 1899. During 1899 and 1900 he installed instruments and switchboards throughout the state of Ohio for the Central Union Telephone Company. From 1900 to 1903 he held the positions of wire chief and inspector in the Columbus, Ohio, office of the Central Union company. He was employed as telephone engineer by the Central District and Printing Telegraph Company, Pittsburgh, Pa., from 1903 to 1905, and by the American Telephone and Telegraph Company, Boston, Mass., during 1905 and 1906. In 1906 he became chief engineer of the Providence (R. I.) Telephone Company. From 1916 to 1922 he was superintendent of plant for that company, and was named division superintendent of plant for the New England Telephone and Telegraph Company. Since 1924 he has been a staff engineer of that company.

M. M. Rockwell (A '28, M '35) product research engineer, Lockheed Aircraft Corporation, Burbank, Calif., has been awarded the $100 industrial prize of the American Welding Society as co-author of the paper, "The Effect of Welding Spacing on the Strength of Spot-Welded Joints," published in the October 1942 *Welding Journal*. Born July 25, 1902, in Philadelphia, Pa., Mrs. Rockwell received the degree of bachelor of science from the Massachusetts Institute of Technology in 1925 and the degree of electrical engineer from Stanford University in 1926. In 1926 she joined the Southern California Edison Company Ltd., Los Angeles, and worked as testman, laboratory technician, and technical assistant until 1931. In 1931 she was made assistant electrical engineer for the Metropolitan Water District of Southern California. She entered the employ of the Lockheed Corporation in 1938 as plant electrical engineer. In 1929 she was awarded the AIEE initial paper prize for the Pacific Coast District.

H. W. Tenney (M '36, F '43) assistant director, research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been made assistant to the vice-president in charge of the company's Pittsburgh divisions. Mr. Tenney has been associated with the Westinghouse company since 1920 when he was employed as a draftsman in the switchboard department. Transferred to the materials and process engineering department in 1922, he held the positions of laboratory foreman, section engineer, and division engineer in charge of the high-voltage, engineering, high-power, chemical and physical, and central engineering laboratories. In 1936 he became manager of the central engineering laboratory department, and manager of the new-products division when it was organized in 1937. He was made manager of the engineering laboratories and standards department in 1938 and assistant director of research laboratories in 1941.

W. L. Cisler (M '35) formerly assistant chief engineer, Public Service Gas and Electric Company, Newark, N. J., has resigned to join the Detroit (Mich.) Edison Company. Graduating from Cornell University in 1922, Mr. Cisler entered the employ of the Public Service Gas and Electric Company as a cadet engineer later becoming test engineer at the company's Marion and Kearny, N. J., generating stations; assistant chief engineer at its Paterson, N. J., station; and chief engineer at the Marion station. In 1931 he was made planning and installation engineer; in 1935 general superintendent; in 1936 assistant general manager; and in 1938 assistant chief engineer. In 1941 he was appointed to the staff of the power coordinator of the Office of Production Management, Washington, D. C., and later served as chief of equipment production in the power section of the Office of War Utilities.

K. W. Jarvis (A '25, M '34) formerly consulting engineer, Winnetka, Ill., is now vice-president of the Sheridan Electro Corporation, Chicago, Ill. Mr. Jarvis commenced his career in the radio field in the radio laboratory of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1923. During subsequent employment with several radio companies he was active in the evolution of radio design. He has held the positions of assistant chief engineer and engineering director for the Zenith Corporation, Chicago, Ill., from 1932 to 1935; vice-president of the Norwalk Engineering Corporation, South Norwalk, Conn., during 1936 and 1937; and chief engineer of the Seeburg Radio Corporation, Chicago, Ill., in 1938. Since 1939 he has practiced as consulting engineer. He is a member of the Institute of Radio Engineers and has published many technical articles.

W. F. Hess (A '32, M '41) assistant professor of metallurgical engineering, and head of the welding laboratory, Rensselaer Polytechnic Institute, Troy, N. Y., has been awarded the $100 university prize of the American Welding Society as co-author of the paper "The Spot Welding of 0.040 In. SAE X-4130 Steel," published in the October 1942 *Welding Journal*. Doctor Hess was graduated from Rensselaer Polytechnic Institute in 1925 with the degree of electrical engineer and in 1928 received the degree of doctor of engineering from that institution. He served as instructor in electrical engineering and physics at Rensselaer Polytechnic Institute from 1928 to 1930. In 1930 he was made assistant professor in those subjects and in 1938 became assistant professor in metallurgical engineering and head of the welding laboratory. He is a member of the Society for the Promotion of Engineering Education.

F. M. Farmer (A '02, F '13) vice-president and chief engineer, Electrical Testing Laboratories, New York, N. Y., has been elected president of the United Engineering Trustees, Inc. He has represented AIEE on the board of the UET since 1937. Mr. Farmer has been connected with the Electrical Testing Laboratories since 1903 as technical assistant, engineer, chief engineer, and vice-president. A past president of AIEE, the American Society for Testing Materials, and the American Welding Society, he is also a past chairman of the Engineering Foundation and the standards council of the American Standards Association. In addition he is a fellow of the American Association for the Advancement of Science and a member of the American Society of Mechanical Engineers, and the Illuminating Engineering Society.

F. J. Vogel (A '21, M '41) formerly consulting engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has been appointed professor of electrical engineering at Illinois Institute of Technology, Chicago. Professor Vogel received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1915 and, after serving in the United States Navy, entered the employ of the Westinghouse company in 1919 as transformer design engineer. Later he was made division engineer in charge of large power transformer design and in 1940 consulting engineer for the transformer division. Author of many AIEE papers and other technical articles, he has served on the electrical machinery committee, and the electrometallurgy and electrochemistry committee, as well as various subcommittees.

E. A. Johnson (A '35) plant extension engineer. Southern New England Telephone Company, New Haven, Conn., has been appointed chief engineer. Graduating from Pratt Institute in 1919, Mr. Johnson worked for a short time for the Toledo (Ohio) Railways and Light Company and for the Winchester Repeating Arms Company, New Haven. In 1920 he entered the employ of the telephone company as an engineering assistant in the office of the traffic engineer. In 1930 he became traffic engineer. He was assigned to the chief engineer's office as plant extension engineer in 1934. **R. W. Pursell** (A '30) engineer of construction program, succeeds Mr. Johnson as plant extension engineer. He has been employed by the telephone company since 1929.

W. W. Ege (A '23, M '32) formerly district manager, Copperweld Steel Company, Chicago, Ill., has been made general manager of sales for that company at Glassport, Pa. Mr. Ege, who is a graduate of Lewis Institute, has been employed by the Copperweld company since 1925, first in the engineering department, and since 1930 as manager of the Chicago office. **Henry Oberle** (A '23, M '36) formerly superintendent of electric distribution and transmission, Queens Borough Gas and Electric Company, New York, N. Y., has been appointed eastern sales manager for the Copperweld company. A graduate of the University of Montana, he joined the Queens Borough company in 1925 as assistant superintendent of distribution and in 1926 was made superintendent.

L. F. Fuller (A '12, F '23) formerly head of the electrical engineering department, University of California, Berkeley, has joined the engineering department of the Joshua Hendy Manufacturing Company, Sunnyvale, Calif. Professor Fuller had been on the staff of the University of California since 1930. As chief electrical engineer for the Federal Telephone Company, New York, N. Y., during World War I, he designed and supervised manufacture and installation of transoceanic apparatus for the United States Government in the Philippine and Hawaiian Islands, Alaska, Guam, the Canal Zone, Porto Rico, and France. From 1917 to 1919 he was a member of the antisubmarine group of the National Research Council.

E. S. Lee (A '20, F '30) engineer, general engineering laboratory, General Electric Laboratory, Schenectady, N. Y., has been elected chairman of the Engineers Council for Professional Development. Mr. Lee holds the degrees of electrical engineer (1913) from the University of Illinois, and bachelor and master of science from Union College (1915). He entered the general engineering laboratory of the General Electric Company in 1919, becoming assistant engineer in 1928 and engineer in charge in 1931. A former vice-president (1940–42) of AIEE, he is also a member of the American Society of Mechanical Engineers, the Institute of Radio Engineers, the Newcomen Society, Etta Kappa Nu, Tau Beta Pi, and Sigma Xi.

Arthur Slepian (A '38) formerly general manager, Wheeler Insulated Wire Company, Bridgeport, Conn., has been appointed vice-president of the company. Mr. Slepian received the degree of bachelor of science from Massachusetts Institute of Technology in 1922 and the degree of master of science from Harvard University in 1923. From 1923 to 1925 he was entered in the student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1925 he joined the Wheeler company to work on the development of new types of wire and in 1926 became assistant general manager. He is a member of the American Institute of Mining and Metallurgical Engineers.

S. M. Dean (A '25, M '41) formerly chief assistant superintendent of electrical system, Detroit (Mich.) Edison Company, has been appointed chief engineer of the system. Mr. Dean was graduated from Michigan State College in 1914 and entered the test course of the General Electric Company, Schenectady, N. Y., in 1916. He was transferred to the general office of the commercial department in 1918 and became sales engineer in 1919. In 1924 he was made assistant manager of the company's Detroit office. Joining the Detroit Edison company in 1925, he became senior electrical engineer in 1927. In 1930 he was made chief assistant superintendent.

Vannevar Bush (A '15, F '24) president, Carnegie Institution of Washington (D. C.), recently was awarded the Holley Medal of the American Society of Mechanical Engineers for "leadership and inventions in easing applied mathematics from computational barriers; and particularly for the differential analyzer that has enlarged differential equation analysis, thereby providing improved analyses in such fields as atomic physics, cosmic rays, ballistics, and automatic control and improved opportunities for understanding various electrical, mechanical, and other physical systems associated with engineering."

F. S. Wilhoit (A '03) purchasing agent, Cutler-Hammer, Inc., Milwaukee, Wis., has retired. Mr. Wilhoit commenced his career as construction engineer for the Sprague Electric Company, Chicago, Ill., in 1898. In 1902 he entered the employ of the Cutler-Hammer as sales engineer and later that year was made assistant superintendent of the company, the position he held until 1909. From 1909 to 1924 he was manager of the printing equipment department. After a period as sales engineer from 1925 to 1932, he became purchasing agent of the company in 1933.

G. W. Spaulding (A '24, M '32) formerly assistant chief engineer, Pennsylvania Water and Power Company, Baltimore, Md., has been appointed vice-president of the company. Mr. Spaulding entered the employ of the Pennsylvania Water and Power Company in 1924 as test engineer. In 1925 he was made assistant chief of tests in the company's hydroelectric and steam plants at Holtwood, Pa. From 1928 to 1938 he held the position of assistant to the general superintendent of the company. In 1939 he became assistant chief engineer.

W. J. Piper (M '39) engineer, meter department, Detroit (Mich.) Edison Company, has been appointed assistant superintendent of meters for that company. A graduate of the University of Michigan, Mr. Piper was a technical assistant in the meter department from 1923 to 1929. Since 1929 he has worked as an engineer in the department. **O. E. Hauser** (A '20, M '32) has been appointed senior engineer in the meter department. Mr. Hauser also has been an engineer in the meter department since 1929.

E. H. Snyder (A '27, M '33) formerly assistant to the chief engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed assistant chief engineer of the electrical-engineering department. A graduate of Lehigh University, Mr. Snyder entered the employ of the Public Service company as a cadet engineer in 1923. Assigned to the distribution engineer's office in 1926, he took charge of a planning group in that office in 1930. In 1937 he was appointed assistant to the chief engineer.

H. R. Winters (A '37) formerly assistant sales manager of the central division, Oklahoma Gas and Electric Company, Sapulpa, has been placed in charge of sales for that division. Mr. Winters has been employed by the company since 1928 and has been attached to the commercial office of the central division since 1937. **R. L. McIntire** (A '34) formerly chief electrician at Sapulpa, has been appointed assistant superintendent of the company's Shawnee district.

A. S. Walker (A '27) formerly operating engineer, New England Power Service Company, Boston, Mass., has been appointed assistant vice-president. He was engaged first in maintenance work for the company during 1913. In 1914 he became station operator and in 1916 load dispatcher. He was made chief load dispatcher in 1919 and superintendent of distribution in 1921. From 1930 to 1941 he was assistant to the general manager. In 1942 he was made operating engineer.

E. K. Goss (A '33) formerly general plant supervisor, Indiana Bell Telephone Company, Indianapolis, has been appointed acting general plant manager. Mr. Goss has been employed by the Indiana Telephone company since 1920 as telephone facilities engineer, and plant engineer and supervisor. **J. W. Quinlan** (M '35) formerly general plant employment supervisor, has been appointed division plant superintendent.

L. R. Mapes (M '29, F '37) formerly general manager, state area, Illinois Bell Telephone Company, Chicago, has been appointed assistant vice-president. Mr. Mapes, who graduated from Columbia University in 1913, has been associated with the Illinois company since 1925 when he became equipment and building engineer. In 1928 he was appointed chief engineer and in 1938 general manager of the state area.

H. M. Archer (A '38) formerly research engineer, Detroit (Mich.) Edison Company,

has been appointed director of research of the Detroit Research Laboratories, Inc., recently organized to do independent general physical research. Mr. Archer has been with the Detroit Edison Company since he received the degree of bachelor of electrical engineering from Rensselaer Polytechnic Institute in 1937. He is the author of articles on infrared drying.

L. K. Sillcox (M '19, F '31) first vice-president, New York Air Brake Company, Watertown, recently was awarded the Medal of the American Society of Mechanical Engineers for "his pre-eminent and permanent contributions to the art and science of engineering, of transportation, of education, and the fine art of living. And for his ingratiating, inspiring influence upon the lives of men."

E. O. Jones (A '29, M '35) formerly sales engineer, industrial department, General Electric Company, Schenectady, N. Y., has joined the engineering staff of the Cook Electric Company and will head its new eastern division office at Greenwich, Conn. A graduate of Massachusetts Institute of Technology, Mr. Jones had been employed by the General Electric Company since 1926.

R. C. Griffith (A '35) formerly director of research, Heald Machine Company, Worcester, Mass., has been appointed manager of engineering and research, Denison Engineering Company, Columbus, Ohio. Prior to joining the Heald company in 1939 as director of research, Mr. Griffith had been employed by the General Electric Company Schenectady, N. Y., since 1926.

Francis Blossom (A '02, M '13) partner, Sanderson and Porter, consulting engineers, New York, N. Y., recently was made an honorary member of the American Society of Mechanical Engineers, "because of his many years of engineering and war usefulness; his courage, sound judgment, and high standards; engineers nationwide, hold him in the highest esteem."

T. D. Graybeal (A '38) instructor in electrical engineering at the University of California, Berkeley, was reported incorrectly to be a graduate of the University of California in the July issue of *Electrical Engineering*. Mr. Graybeal received the degree of bachelor of science from the University of Colorado in 1937.

OBITUARY • • • •

B. E. Sunny (A '03, F '13) retired, died October 5, 1943, in Chicago, Ill. Born May 22, 1856, in Brooklyn, N. Y., Mr. Sunny commenced his career as a telegraph operator for the Atlantic and Pacific Telegraph Company, Chicago, Ill., in 1873 and in 1876 became a telegraph manager. In 1879 he became superintendent for the Chicago Telephone Company and in 1888 president of the Chicago Arc Light and Power Company. In 1890 as western manager he joined the Thomson-Houston Electric Company which became the General Electric Company in 1892. Mr. Sunny remained with the latter company as western manager and vice-president until 1908 when he returned to the telephone industry as president of the Chicago Telephone Company. In 1922 he was elected chairman of the board. In addition he held the positions of president of the Wisconsin Telephone Company from 1911 to 1922 and chairman of the board from 1922 to 1930, as well as president of the Central Union, Michigan State, and Cleveland (Ohio) Telephone Companies from 1911 to 1922 and chairman of the board from 1922 to 1930. He was director and member of the executive committees of many electrical, railway, and utility companies for many years. As trustee, director, and committeeman, he served various organizations devoted to juvenile welfare and was also a member of the Western Society of Engineers, the Art Institute of Chicago, the Field Museum of Natural History, the Chicago Historical Society, and the executive committee of the American Red Cross.

Frederick Darlington (A '02, F '13) retired consulting engineer, Great Barrington, Mass., died October 27, 1943. Born at Lincoln University, Pa., April 23, 1867, he received the degree of bachelor of science in chemistry and physics from Pennsylvania State College in 1886. He commenced his career with the Phoenix Bridge and Iron Works, Phoenixville, Pa., in 1887. As a chemist he was employed by the Pittsburgh (Pa.) Testing Laboratory in 1888 and by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., from 1890 to 1892. From 1892 to 1898 he worked as engineer for the United Electric Light and Power Company and the Brush Electric Light Illuminating Company in New York, N. Y. He was associated with the Stanley Instrument Company, Great Barrington, Mass., as vice-president and general manager, and with the Construction Company of America as chief engineer from 1898 to 1903. In 1905 he returned to the Westinghouse company as consulting engineer. During 1913 he served as vice-president and manager of the Alabama Power Company and consulting engineer for Sperling and Company, London, England. From 1914 until his retirement in 1936 he was associated with the Westinghouse company in a consulting capacity. During 1918 he served as consulting engineer to the power section of the War Industries Board.

Leonard Lord Elden (A '03, M '13) retired, died October 21, 1943, Wareham, Mass. Born in Buxton, Me., May 16, 1868, he received the honorary degree of doctor of science from Tufts College in 1928. Doctor Elden commenced his career as dynamo tender for the Merchants Electric Light and Power Company, Boston, Mass., in 1885. From 1888 to 1902 he was employed as an electrician by the Boston Electric Light Company. When the latter company became part of the Edison Electric Illuminating Company, he was appointed chief electrical engineer and he continued as technical adviser to that company until his retirement in 1932. He is credited with invention of several types of circuit breakers as well as other electrical equipment. His AIEE activities included membership on the protective devices committee, 1916–18; the committee on transmission and distribution and its successor, the committee on power transmission and distribution, 1922–32; the committee on safety codes, 1927–30. He was a representative of the National Electric Light Association on the electrotechnical commission of the World Power Conference and also a member of the National Fire Protection Association and the American Standards Association.

F. W. Brockhoff (A '38) safety engineer, Union Electric Company of Missouri, St. Louis, died recently. Mr. Brockhoff was born September 1, 1886, in St. Paul, Minn. His first position in the electrical field was apprentice wireman from 1903 to 1906 for Charles J. Sutter, Electrical Contractor. In 1906 he became apprentice machinist for the Emerson Electric Company and in 1908 for William Wurdach Electric Manufacturing Company. From 1909 to 1916 he served as electrical inspector in the central department of the Quartermaster Corps of the United States Government. He joined the service and sales department of the Mancha Storage Battery Locomotive Company in 1916 and in 1921 the farm lighting division of the Western Electric Company. In 1924 he entered the employ of the Union Electric Light and Power Company, St. Louis, to do electrical maintenance work. He was made relay tester in 1928 and foreman in 1930. In 1935 when the company name was changed to the Union Electric Company of Missouri, he was named general foreman in the substation division. In 1942 he was appointed safety engineer.

Francis Clifford Feiring (M '43) electrical contractor, Plainfield, N. J., died September 19, 1943. He was born in Plainfield in 1898. In 1919 he entered the employ of the Aero Alarm Company, New York, N. Y., as traveling inspector of fire alarm installations, and in 1921 was made district superintendent. From 1924 to 1931 he was employed as inspector, sales engineer, estimator, and supervisor. In the latter position maintenance of all fire alarm and telephone installations were under his jurisdiction. During 1931 and part of 1932 he worked as subcontractor for Joseph Harper and Son Company, New York. In 1932 he formed the Bruce Engineering

Company, New York, which specialized in marine electrical work. Later he formed the Bruce Electric Company, Inc., which was dissolved in 1941. He was a partner in the Brelco Radio Company, and president of the Brelco Radio Corporation and the Allied Marine Contractors Association. Mr. Feiring was also an associate member of the Society of Naval Architects and Marine Engineers.

John Guistwite Miller (A '41) senior electrical engineer, Corps of Engineers, United States War Department, died in December 1942. He was born July 28, 1910, in Columbia, Pa., and was graduated from Cooper Union Institute in 1928. From 1928 to 1933 he worked as chief electrician and electrical engineer for the Morgan Laundries, Inc., New York, N. Y. As chief engineer for Camp Milford, Inc., New York, from 1933 to 1937, he had charge of building a vacation resort. As electrical engineer he joined the Davidson Electric Company, Brooklyn, N. Y., in 1937 and in 1938 the A. C. Electric Company, Columbia, Pa. In 1940 he entered the employ of the War Department and as chief electrical engineer for the Zone Constructing Quartermaster Army Base, Boston, Mass., had charge of all the electrical work done for the Army in the New England States. In 1941 he was transferred to Omaha, Nebr., as senior electrical engineer, subsequently going to Australia from which he returned in 1942.

Herman A. Tepel (A '23) secretary of the Adalet Manufacturing Company, Cleveland, Ohio, died July 13, 1943. Mr. Tepel was born in Dusseldorf, Germany, July 31, 1882. He commenced his career as an apprentice construction electrician in Pittsburgh, Pa., in 1899 and in 1907 was superintendent of construction for the L. A. Comstock Company, Pittsburgh, Pa. From 1908 to 1910 he worked as electrical contractor in Louisville, Ky. He was connected with the Marine Electric Company, Louisville, as vice-president, estimator, and engineer from 1911 to 1914. During 1915 he was superintendent of construction for the F. A. Clegg Company, Louisville. From 1916 to 1920 he was superintendent of construction for the Cuyahoga Power Construction Company, Cleveland, Ohio. In 1920 he joined the Dingle-Clark Company, Cleveland, as superintendent of construction and estimator and in 1925 became chief engineer of the company. He was made secretary of the Adalet company in 1937.

John Willis Hines (A '22) engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y., died September 30, 1943. Born in Riverton, Conn., December 12, 1891, he was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in electrical engineering in 1914. He commenced his association with the American Telephone company in the outside plant department in 1914. From 1917 to 1919 he served in the United States Navy. In 1919 he returned to the engineering department of the American Telephone company where he was engaged in preparing specifications for outside construction. Since 1929 he had been a member of the foreign wire relations section and had worked with the power industry on co-ordination problems. Recently he participated in the preparation of Part II of the fifth edition of the National Electrical Safety Code as a member of several of the technical subcommittees, the committee preparing the discussion, and the interpretations committee.

J. H. Roddey (A '06, M '13) superintendent of operation, Duke Power Company, Charlotte, N. C., died October 18, 1943. Mr. Roddey, who was born January 8, 1881, in Rock Hill, S. C., was graduated from Clemson Agricultural and Mechanical College with the degree of bachelor of science in electrical engineering in 1901. After working in the testing department of the General Electric Company, Schenectady, N. Y., from 1902 to 1906, he joined the Southern Power Company, Charlotte, which later was consolidated with the Duke Power Company. He assumed the duties of superintendent of operation in 1907, the year that position was created.

Clifton V. Edwards (A '99) lawyer and member of the firm, Edwards, Bauer, and Pool, New York, N. Y., died October 2, 1943. Mr. Edwards, who was born in Washington, D. C., May 21, 1872, attended the Columbian Law School and the law school of New York University. He specialized in patent law and since 1894 had been engaged in prosecuting applications for patents, patent litigation, and general legal business relating to patents in New York State. He was admitted to practice in the Federal courts and, in 1893, to the bar in Washington, D. C., as well.

Hervey D. Plenge (A '24) electrical engineer, General Electric Company, Schenectady, N. Y., died June 12, 1943. Born in Charleston, S. C., January 12, 1890, he was graduated from Clemson Agricultural and Mechanical College with the degree of bachelor of science in electrical engineering in 1910. From 1910 to 1912 he was employed in the testing department of the General Electric Company. In 1912 he was transferred to the a-c turbine engineering department.

John L. Bauerle (A '37) engineering assistant, Cleveland (Ohio) Electric Illuminating Company, died September 25, 1943. Born November 25, 1907, in South Fork, Pa., he received the degree of bachelor of science in electrical engineering from Carnegie Institute of Technology in 1929. That year he joined the Cleveland Electric company where he worked on substation design.

MEMBERSHIP ..

Recommended for Transfer

The board of examiners, at its meeting on November 18, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Abbott, A. L., engr., National Electrical Manufacturers Association, New York.
Bennion, H. S., vice-president & managing director, Edison Electric Institute, New York.
Manson, R. H., vice-president & General Mgr., Stromberg-Carlson Co., Rochester, N. Y.
Walton, P. J., application engr., General Elec. Co., Philadelphia, Pa.
Whitaker, W. G. H., chief engr., New Jersey Bell Telephone Co., Newark, N. J.

5 to grade of Fellow

To Grade of Member

Bacon, F. S., asst. mgr., Central Station Div., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Bankus, J., chief engr., Portland General Elec. Co. Portland, Oreg.
Bartles, S. P., asst. elec. engr., Eastman Kodak Co. Rochester, N. Y.
Brannin, R. S., project engr., Sperry Gyroscope Co. Inc., Garden City, N. Y.
Brown, G. O., mgr. of distribution, Kansas City Power & Light Co., Kansas City, Mo.
Buckley, J. L., asst. elec. engr., Pacific Gas & Elec Co., San Francisco, Calif.
Chambers, M. A., supt. of telephone & telegraph Standard Oil Co. of Louisiana, Shreveport, La.
Christensen, P. M., chief engr., Colt's Patent Fir Arms Mfg. Co., Hartford, Conn.
Clark, J. H., plant staff asst., Southern Calif. Tel. Co Los Angeles, Calif.
Frey, A. P., asst. supt. of equipment, Baltimore Transi Co., Baltimore, Md.
Glenzer, K. V., engr., Illinois Bell Telephone Co. Chicago, Ill.
Hagenguth, J. H., in charge of high voltage engr. lab. General Elec. Co., Pittsfield, Mass.
Hansell, C. W., research supervisor in charge of Rock Point Lab., RCA, Rocky Point, N. Y.
Hemphill, L. F., section engr., General Elec. Co. Fort Wayne, Ind.
Irwin, J. H., mgr., Atlanta Office, Aluminum Company of America, Atlanta, Ga.
Matzinger, J. R., design engr., Goodyear Aircraft Corp., Akron, Ohio.
Mullin, L. A., asst. prof. of elec. engg., Syracuse University, Syracuse, N. Y.
Onory, G. S., elec. engr., United States Maritime Comm., Oakland, Calif.
Peck, R. R., field engr., Raytheon Mfg. Co., Waltham Mass.
Ripa, J. L., elec. engr., Consolidated Vultee Aircraft Corp., San Diego, Calif.
Ruddell, L. G., elec. engr., Kansas City Power & Light Co., Kansas City, Mo.
Santiago, F., elec. engr., Wellman Engg. Co., Akron, Ohio.
Simmons, H., asst. supt. elec. dept., Pacific Naval Air Base, Fort Hueneme, Calif.
Smith, J. H., asst. prof. of elec. engg., Cornell University, Ithaca, N. Y.
Taylor, P. L., general engg., Allis-Chalmers Mfg. Co., Boston, Mass.
Vonasch, R. W., asst. mgr., Federal and Marine Div., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Weil, R. T., asst. prof. of elec. engg., Manhattan College, New York.
Wolf, Harold, asst. prof. of elec. engg., College of the City of New York, New York.

28 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1943, or February 31, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Agnew, E. A., Goodyear Tire & Rubber Co., Akron., Ohio.
Baer, W. O. (Re-election), Cutler-Hammer, Inc., Milwaukee, Wis.
Bartlett, C. A. (Re-election), Amer. Tel. & Tel. Co., Chicago, Ill.
Brims, G. J., Int. Tel. & Tel., New York, N. Y.
Brout, D. W., Anchor Mfg. Co., Manchester, N. H.

Chadwich, G. L. (Re-election), Lord Elec. Co., Inc., Boston, Mass.
Clarke, C. A. (Re-election), Federal Tel. & Radio Corp., East Newark, N. J.
Clos, C., New York Tel. Co., New York, N. Y.
Colburn, F., Northampton Polytechnic, London, England.
Crocker, T. D., Northern States Pr. Co., Minneapolis, Minn.
Cummins, H. C., Northern States Pr. Co., Minneapolis, Minn.
Das Anurendra, C. (Re-election), Rajkot State Elec. S. Co., Rajkot, India.
Duerr, K. B., Western Union Tel. Co., New York, N. Y.
Eddie, J., George G. Sharp, Cons. Engr., Oakland, Calif.
Fronmuller, T. C. (Re-election), Pacific Gas & Elec. Co., San Francisco, Calif.
Gieh, H. B., Consulting & Design Engr., Dallas, Tex.
Green, A. P., A. P. Green Fire Brick Co., Mexico, Mo.
Haggart, J. D., British Columbia Elec. Ry. Co., Vancouver, B. C., Can.
Hastie, J. S., Scottish Cables, Ltd., Renfrew, Scotland.
Hayman, R. E., Rural Elec. Adm., Oklahoma City, Okla.
Hoffmann, W. W. (Re-election), Gen. Elec. X-Ray Corp., Chicago, Ill.
Hoover, R., Western Union Tel. Co., New York, N. Y.
Hudson, H. H. (Re-election), Elec. Storage Battery Co., New York, N. Y.
Jones, J. R., Douglas Aircraft Co., Inc., Los Angeles, Calif.
Kearns, J. L., Federal Public Housing Authority, Kansas City, Mo.
Kerr, C. L. (Re-election), Gen. Elec. Co., Denver, Colo.
Matz, C. L. (Re-election), Commonwealth Edison Co., Chicago, Ill.
Menasseaux, A. R., Bell Tel. Labs., Inc., New York, N. Y.
Miller, J. R., Bendix Aviation Corp., Brooklyn, N. Y.
Moyer, L. M. (Re-election), General Elec. Co., Portland, Oreg.
Peckham, J. W., Bristol Co., Waterbury, Conn.
Rendel, G. H., Carnegie-Illinois Steel Corp., Pittsburgh, Pa.
Russler, F., American Tel & Tel. Co., Chicago, Ill.
Straiton, A. W., University of Texas, Austin, Texas.
Villeneuve, J. A., Marine Industries, Ltd., Sorel, Que., Can.
West, H. E., Amer. Tel. & Tel. Co., Philadelphia, Pa.
Zeitlin, A., Rogers Diesel & Aircraft Corp., New York, N. Y.

37 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Barrett, S. R. (Re-election), Cobble Mountain Power Station, Westfield, Mass.
Borders, C. R., Harvard University, Cambridge, Mass.
Emerson, H. J., Eastman Kodak Co., Rochester, N. Y.
Gallagher, J. J., Jr., General Elec. Co., Bridgeport, Conn.
Gardiner, C. B., Central N. Y. Power Corp., Potsdam, N. Y.
Gehringer, P. J., Gen. Elec. Co., Schenectady, N. Y.
Millar, N. B., Gen. Elec. Co., West Lynn, Mass.
Ransom, M. E., Jr., Graybar Elec. Co., Binghamton, N. Y.
Saretsky, S., Holtzer & Cabot Elec. Co., Boston, Mass.
Seibert, W. H., Western Union Tel. Co., Syracuse, N. Y.
Spitzer, C. P., Yale University, New Haven, Conn.

2. Middle Eastern

Blatchford, J. W., Southern Wood Preserving Co., Philadelphia, Pa.
Bragg, S. J., Mack Mfg. Corp., Allentown, Pa.
Cochener, R. L., Gen. Elec. Co., Philadelphia, Pa.
Day, P. H., National Bureau of Standards, Washington, D. C.
Enion, R. A., Bell Tel. Co. of Penna., Philadelphia, Pa.
Farmer, M. H., Ohio Edison Co., Akron, Ohio.
Garrison, R. E., Jr., Naval Research Lab., Washington, D. C.
Hartzell, R. C. (Re-election), Cinn. Gas & Elec. Co., Cincinnati, Ohio.
Janes, A. G., General Elec. Co., Erie, Pa.
Jennings, L. D., Westinghouse E. & M. Co., Sharon, Pa.
Johnson, G. E., U. S. Dept. of Commerce, Washington, D. C.
Jones, S., Heinemann Circuit Breaker Co., Trenton, N. J.
Locks, A. J., Westinghouse Elec. Int'l. Co., Washington, D. C.
McKinney, M., Locke Insulator Corp., Cincinnati, Ohio.
Musselman, F. L., Gen. Elec. Co., Philadelphia, Pa.
Pask, D. A., Lieut., RNVR, Washington, D. C.
Polich, A. L., Johns Hopkins Univ., Silver Spring, Md.
Rasmusen, R. P. C., Babcock & Wilcox Co., Barberton, Ohio.
Sarson, (Miss) K. O., U. S. Navy Dept., Camden, N. J.
Schneeberger, R. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Walley, O. C., Westinghouse Elec. & Mfg. Co., Lima, Ohio.

3. New York City

Aichele, P. F., Sperry Gyroscope Co., Inc., Brooklyn, N. Y.
Armiento, L., Ward Leonard Elec. Co., New York, N. Y.
Berry, C. D., Nat. Union Radio Corp., Newark, N. J.
Binkowski, E. W., West. Elec. Elevator Co., Jersey City, N. J.
Craine, R. B., James Stewart Associates, New York, N. Y.
Crenenberg, A. W., Todd Shipyards Corp., Hoboken, N. J.
Genodman, M., Todd-Hoboken Shipyard, Hoboken, N. J.
Goodwin, R. F., Monitor Controller Co., New York, N. Y.
Hackett, J. W. (Re-election), The Okonite Co., New York, N. Y.
Hillig, K. F., S. J. O'Brien, Inc., New York, N. Y.
Johnson, H. M., Baker & Co., Newark, N. J.
Jurick, E. F., Radio Television Institute, New York, N. Y.
Lowe, G. G. (Re-election), The Feeile Co., Brooklyn, N. Y.
Mageoch, N. H., Western Elec. Co., Kearny, N. J.
Mayerbach, A. H., S. J. O'Brien, Inc., New York, N. Y.
Price, R. D., U. S. War Dept., Newark, N. J.
Repose, F., Radio Television Institute, New York, N. Y.
Ridley, B. W., U. S. Navy Yard, Brooklyn, N. Y.
Rioux, R. P., Long Island Lighting Co., Mineola, N. Y.
Shalhoub, W. J., Automatic Paper Mach. Co., Holyoke, N. Y.
Singalewitch, P., Westinghouse E. & M. Co., Newark, N. J.
Suan, S. Y. Nat. Resources Comm. of China, New York, N. Y.
Teetsel, H., Todd Shipyards Corp., Weehawken, N. J.
Vanina, R. A., Electric Boat Co., Bayonne, N. J.
Wahlstrom, F. A., Lieut., U. S. Army, Red Bank, N. J.

4. Southern

Armstrong, R. W. (Re-election), Chas. T. Main, Inc., Kingsport, Tenn.
Ball, D. J. (Re-election), Newport News Shipbldg. & Dry Dock Co., Newport News, Va.
Bossert, H. F., Signal Corps, U. S. Army, Arlington, Va.
Butterworth, L. A., J. A. Jones Constr. Co., Inc., Brunswick, Ga.
Carson, B. L., Amer. Cast Iron Pipe Co., Birmingham, Ala.
Edwards, J. P., Duke University, Durham, N. C.
Emmons, W. M. (Re-election), Westinghouse Elec. & Mfg., Atlanta, Ga.
Goss, C. G., Louisiana Polytechnic Inst., Ruston, La.
Hanchey, W. R., Carolina Pr. & Lt. Co., Raleigh, N. C.
Keller, D. F., Duke University, Durham, N. C.
Maher, L., Ensign, U. S. Navy Yard, Charleston, S. C.
Palmer, J. E., Jr. (Re-election), U. S. Navy, Norfolk, Va.
Rudesill, R., Tennessee Valley Authority, Wilson Dam, Ala.

5. Great Lakes

Anderson, C. J., Barber Colman Co., Rockford, Ill.
Becker, H. I., Jr., General Elec. Co., Fort Wayne, Ind.
Christian, T. R., Cutler-Hammer, Inc., Milwaukee, Wis.
Cogger, C. S., C. M. Hall Lamp Co., Detroit, Mich.
Doyen, J. E., U. S. Maritime Comm., Chicago, Ill.
Ecker, H. W., Minn. Min. & Mfg. Co., St. Paul, Minn.
Hackett, H. E., Gen. Elec. Co., Fort Wayne, Ind.
Holt, D. L., Gen. Motors Corp., Anderson, Ind.
Hopkins, T. A., Caterpillar Tractor Co., Peoria, Ill.
Hutchinson, G., Square D Co., Milwaukee, Wis.
Markese, J., Delta-Star Elec. Co., Chicago, Ill.
Markese, S. D., Delta-Star Elec. Co., Chicago, Ill.
Moore, S. A. (Re-election), Prime Mfg. Co., Milwaukee, Wis.
Osterberg, R. M., James Stewart & Co., Chicago, Ill.
Powers, W. R., Gen. Elec. Co., Fort Wayne, Ind.
Ritchie, E. A., Kurz & Root Co., Appleton, Wis.
Steele, H. P., Benjamin Elec. & Mfg. Co., Des Plaines, Ill.
Welch, W. E. (Re-election), Minn. Honeywell Regulator Co., Minneapolis, Minn.
Young, C. G., Gen. Elec. Co., Fort Wayne, Ind.

6. North Central

Schmidt, A. W., Bureau of Reclamation, Denver, Colo.

7. South West

Armstrong, J. F., El Paso Elec. Co., El Paso, Texas
Crosthwait, G. N., Texas Elec. Serv. Co., Wichita Falls, Texas.
DePrato, E. W., General Elec. Co., Houston, Texas.
Gillam, C. E., Kansas City Pr. & Lt. Co., Kansas City, Mo.
Glomski, W. E., S. W. Bell Tel. Co., St. Louis, Mo.
Green, J. D., Boeing Airplane Co., Wichita, Kans.
Houser, K. O. (Re-election), Kansas Gas & Elec. Co., Wichita, Kans.
Johnson, L., Amer. Tel. & Tel. Co., St. Louis, Mo.
Joyce, S. F. (Re-election), Union Elec. Co. of Mo., St. Louis, Mo.
Koenig, W. J., Amer. Tel. & Tel. Co., St. Louis, Mo.
Lyons, E. F., WKY Radiophone, Inc., Oklahoma City, Okla.
Martin, K. H., Kansas State College, Manhattan, Kans.
Morris, R. E., Rural Elec. Adm., St. Louis, Mo.
Phillips, A., Allis-Chalmers Mfg. Co., Beaumont, Texas.
Phillips, F. L. (Re-election), Kansas City Pr. & Lt. Co., Kansas City, Mo.
Phillips, W. R., Moloney Elec. Co., St. Louis, Mo.
Powell, L. E., Joslyn Southwest Co., Dallas, Texas.
Robbins, R. B., Penn. Shipyards, Inc., Beaumont, Texas.
Stubbins, W. F., Capt., U. S. Army, San Antonio, Texas.
Turner, J. C., S. W. Bell Tel. Co., Oklahoma City, Okla.
Wanko, A. N., Moloney Elec. Co., St. Louis, Mo.
Warner, W. C., Penn. Shipyards, Inc., Beaumont, Texas.
White, R. E. (Re-election), Gulf States Utilities Co., Beaumont, Texas.
Wuetherich, R. A., Union Elec. Co. of Mo., St. Louis, Mo.

8. Pacific

Adams, P. H., San Diego Gas & Elec. Co., San Diego, Calif.
Beach, W. J., 2 Chapel St., Placerville, Calif.
Bertoler, E. C., 1st Lt., U. S. Army, San Bernardino, Calif.
Braud, H. M., U. S. War Dept., Presidio of San Francisco, Calif.
Churchill, P. K., Line Material Co., San Francisco, Calif.
Day, C. R., Modesto Irrigation District, Modesto, Calif.
Dimmick, M. A., Richmond Shipyard #3, Richmond, Calif.
Domino, F. E., U. S. Bureau of Reclamation, Phoenix, Ariz.
Ferraro, F. D., Vultee Aircraft, Inc., Vultee Field, Calif.
Gaylord, J. M., Byron Jackson Pump Co., Los Angeles, Calif.
Irish, F. M. (Re-election), Central Arizona Lt. & Pr. Co., Phoenix, Ariz.
King, F. D., Consolidated Vultee Aircraft Corp., Downey, Calif.
King, G. C., Consolidated Vultee Aircraft Corp., Downey, Calif.
Koepke, W. E., Kaiser Shipyard, Richmond, Calif.
Kremer, I. A., Consolidated Vultee Aircraft Corp., Vultee Field, Calif.
Murray, B. A., Electric Supplies Dist. Co., San Diego, Calif.
Navin, J. F., U. S. Navy, Vernon, Calif.
Richardson, J. W., Consolidated Vultee Aircraft Corp., Vultee Field, Calif.
Rude, M., Ensign, USNR, San Francisco, Calif.
Thompson, I. F., Consolidated Vultee Aircraft Corp., Vultee Field, Calif.
Vinoff, I., Western Pipe & Steel Co., So. San Francisco, Calif.
Watson, J. C., U. S. Maritime Comm., Oakland, Calif.

9. North West

Ley, H. T., Westinghouse Elec. & Mfg. Co., Portland, Oreg.
Porter, W., Aluminum Co. of America, Troutdale, Oreg.
Volpe, J. S. (Re-election), Portland Gen. Elec. Co. Portland, Oreg.

10. Canada

Edmonds, A., Swansea Hydro-Elec. System, Swansea, Ont., Can.
Irwin, G. J., Philco. Corp. of Canada, Toronto, Ont., Can.

Elsewhere

Aguila, R. M., Elec. Contractor, Coldel Valle, D. F., Mex.
Brun, O. F. (Re-election), Allis-Chalmers de Mexico, Mexico, D. F., Mex.
Garcia, J. C., Productores De Energia Elec. "ElSalto" La Piedad, Mich., Mex.
Luna Fernando, O., Dir, del Catastro Depto del D. F. Mexico, D. F., Mex.
Mendoza Leonardo, V., Cia. West. Elec. Int'l. Co., Mexico City, Mex.
Molina, U. G., Amacuzac Hydraulic Elec. Co., Mexico City, Mex.
Perez, J. G., Engineer, Mexico, D. F., Mex.
Querejeta, A., Cia. Hulera Euzkadi & Goodrich, Mexico City, Mex.
Valdovinos, R. L., Elec. Contr., San Juan, P. R.

Total to Grade of Associate
United States and Canada, 140
Elsewhere, 9

OF CURRENT INTEREST

ECPD Forges Ahead Despite Wartime Difficulties

Although wartime conditions have influenced many of the activities of the Engineers' Council for Professional Development during the past year, nevertheless progress in furthering the aims of ECPD has been achieved, and attention has been given to problems arising directly as a result of the war. These were among the more important facts brought out at the 11th annual meeting of ECPD held October 23, 1943, in New York, N. Y. Joint organization of eight national engineering societies, ECPD has as its general objective the enhancement of the professional status of the engineer.

Completion of plans for pursuing ECPD activities at "the level of the individual" was one of the most important accomplishments of the year. At the 1942 annual meeting (*EE, Dec. '42, pp. 626–30*) the council approved a plan of action proposed by AIEE representative J. F. Fairman (F '35), and, during the past year, the plan has been approved by the boards of the constituent societies. At the 1943 meeting, publication of a booklet, prepared by Mr. Fairman, outlining the plan and how to put it into action, was authorized. Details are reported elsewhere in this issue.

Among other important actions was approval of a statement of the "Faith of the Engineer," prepared by the ECPD committee on ethics headed by AIEE Past President D. C. Jackson (F '12); full text of this statement is given in a separate item. Progress in the preparation of the previously authorized "Manual for Junior Engineers" was reported by Chairman E. S. Lee (F '30) of the ECPD committee on professional training. Mr. Lee announced that W. E. Wickenden (F '39) engineering educator and president of Case School of Applied Science, Cleveland, Ohio, has accepted authorship of the manual and now has it under preparation. Annual reports of the various committees of ECPD and of the representatives of the constituent societies were presented.

Most severely curtailed by wartime conditions of all ECPD activities during the past year was the curricula-accrediting program. Only two new courses, both in chemical engineering, were accredited at the 1943 annual meeting.

E. S. Lee, newly appointed AIEE representative on the council, was elected chairman for the year 1943–44. Other officers elected and committees appointed for the year are reported separately. Expenditures during the year 1942–43 were reported as $10,642.14, and a budget totalling $12,150.00 for 1943–44 was adopted. ECPD income is derived chiefly from contributions from the constituent societies (AIEE $1,700 for 1943–44); for the past several years, these have augmented by an annual contribution from the Engineering Foundation which has allotted $5,000 for 1943–44.

Supplementing the morning and afternoon sessions of the 1943 annual meeting, a dinner meeting was held at the Engineers Club for the officers and members of the council and officers of the constituent societies. Following dinner was a round-table conference discussion of postwar engineering education.

Officers and Committees

ECPD Officers elected for 1943–44 are:

E. S. Lee (F '30) engineer, General Electric Company, Schenectady, N. Y., *chairman;* James W. Parker, vice-president and chief engineer, The Detroit Edison Company, Detroit, Mich., *vice-chairman;* S. L. Tyler, executive secretary, American Institute of Chemical Engineers, New York, N. Y., *secretary;* R. L. Sackett, assistant to secretary, American Society of Mechanical Engineers, New York, N. Y., *assistant secretary.*

Members of the executive committee are:

E. S. Lee (F '30) *chairman ex-officio;* J. W. Parker, *vice-chairman ex-officio;* George W. Burpee, consulting engineer, Coverdale and Colpitts Co., New York, N. Y.; W. B. Plank, professor of mining, Lafayette College, Easton, Pa.; R. L. Geotzenberger, vice-president, Minneapolis-Honeywell Regulator Co., Philadelphia, Pa.; J. F. Fairman (F '35) assistant vice-president, Consolidated Edison Company of New York, New York, N. Y.; J. B. Challies, vice-president and executive engineer, Shawinigan Water and Power Company, Montreal, Que., Can.; C. C. Williams, president, Lehigh University, Bethlehem, Pa.; S. D. Kirkpatrick, editor, *Chemical and Metallurgical Engineering*, New York, N. Y.; V. M. Palmer, superintendent, industrial engineering department, Kodak Park Works, Eastman Kodak Company, Rochester, N. Y.

The following representatives of ECPD member societies were announced for the 1943–46 term:

Reappointments—R. E. Bakenhus, rear admiral, United States Navy, retired; W. B. Plank, professor of mining, Lafayette College, Easton, Pa.

New appointments—R. L. Geotzenberger, vice-president, Minneapolis Honeywell-Regulator Company,

Faith of the Engineer

Approved by Engineers' Council for Professional Development at its annual meeting October 23, 1943, on recommendation of the ECPD committee on principles of engineering ethics

I am an engineer. In my profession I take deep pride, but without vainglory; to it I owe solemn obligations that I am eager to fulfill.

As an engineer, I will participate in none but honest enterprise. To him that has engaged my services, as employer or client, I will give the utmost of performance and fidelity.

When needed, my skill and knowledge shall be given without reservation for the public good. From special capacity springs the obligation to use it well in the service of humanity; and I accept the challenge that this implies.

Jealous of the high repute of my calling, I will strive to protect the interests and the good name of any engineer that I know to be deserving; but I will not shrink, should duty dictate, from disclosing the truth regarding anyone that, by unscrupulous act, has shown himself unworthy of the profession.

Since the Age of Stone, human progress has been conditioned by the genius of my professional forebears. By them have been rendered usable to mankind Nature's vast resources of material and energy. By them have been vitalized and turned to practical account the principles of science and the revelations of technology. Except for this heritage of accumulated experience, my efforts would be feeble. I dedicate myself to the dissemination of engineering knowledge, and, especially, to the instruction of younger members of my profession in all its arts and traditions.

To my fellows I pledge, in the same full measure I ask of them, integrity and fair dealing, tolerance and respect, and devotion to the standards and the dignity of our profession; with the consciousness, always, that our special expertness carries with it the obligation to serve the public and humanity with complete sincerity.

Philadelphia, Pa.; E. S. Lee (F '30) General Electric Company, Schenectady, N. Y.; George G. Brown, professor of chemical engineering, University of Michigan, Ann Arbor, Mich.; C. R. Young, dean, faculty of applied science and engineering, University of Toronto, Toronto, Ont., Canada; C. E. Lawall, president, West Virginia University, Morgantown, W. Va.

Newly elected committee chairmen for 1943–44 are:

Committee on professional training, John C. Arnell (A '28) manager, personnel co-ordination bureau, Consolidated Edison Co. of N. Y.

Committee on information, S. L. Tyler, secretary, American Institute of Chemical Engineers, New York, N. Y.

Th following committee chairmen were re-elected for the coming year:

Committee on student selection and guidance, A. R. Cullimore, president, Newark (N. J.) College of Engineering.

Committee on engineering schools, D. B. Prentice, president, Rose Polytechnic Institute, Terre Haute, Ind.

Committee on professional recognition, C. F. Scott, professor emeritus of electrical engineering, Yale University, New Haven, Conn.

Report of Chairman

In presenting his annual report for 1942–43, Retiring Chairman R. E. Doherty (F '39) urged that three points of policy be observed carefully if ECPD is to continue to function effectively. He also reported on the contributions to the war effort made by the consultative committee on engineering man power, established under instigation of ECPD officers, and reviewed the accomplishments of the various ECPD committees.

"During my six years on the council and three as chairman," he said, "I have become keenly aware that if the council is to endure and accomplish the purposes for which it was organized, certain principles must be recognized; otherwise the centrifugal forces that have broken other co-operative enterprises in the engineering profession might also break Engineers' Council for Professional Development. It early became clear that we must remove unnecessary internal pressures, which were largely centered upon misunderstandings and matters of detail, and address the attention and energies of the council to its constructive business. In the second place, it became clear also that a distorted conception of purpose must be cleared up. The council's business is defined with reasonable clarity in the charter and is represented by the four standing committees. The growing tendency to regard the work of accrediting curricula as the primary, and perhaps the only significant, purpose was ill advised; the objectives represented by these four committees were *all of them* of great fundamental importance. Finally, and above all, it became clear that the council should stick to its business and not yield to the pressures which are constantly arising for it to interest itself in matters outside, or at the fringe of, its purview. If the council sticks to its purposes as now defined until it reasonably accomplishes them, it will avoid disruptive pressures and will also, I hope, have demonstrated to the constituent bodies that they may with assurance delegate other activities to it if the future should bring new problems that require joint action of a character which the council could appropriately handle. . . .

"Here, then, are three points: We must remove unnecessary internal pressures, not permit purpose to become distorted, and stick to our business. In retiring from the chairmanship this year, I strongly commend these points to the council's perennial consideration.

"Our work has gone forward. One result is improved machinery for doing business. It has seemed clear that neither an educational campaign nor other activities that must be pursued 'at the level of the individual' in order to be effective, could be carried out without the establishment of new machinery or rather the supplying of new links between parts of existing machinery. During the past two years there has been continued study of this problem and discussion of it from time to time in meetings of the executive committee. At the last council meeting a plan drafted by J. F. Fairman, chai man of a special committee on this matter, had reached a stage where the council approved it in principle and authorized him to seek approval of the boards of the constituent organizations. I am happy to report that this carefully constructed plan has been approved by the constituent organizations, and thus the machinery is created for carrying forward our work at the level of the individual engineer and engineering student. . . .

WORK OF CONSULTATIVE COMMITTEE ON ENGINEERING MAN POWER

"The Council has concerned itself indirectly with the problem of professional engineering man power in the war effort," Doctor Doherty declared, in eporting the achievements of the consultative committee on engineering man power. "Since ECPD itself was not, by its charter, in position to deal effectively with this urgent problem without elaborate procedures of approval, the chairman approached it in a way to obtain prompt action, to keep the council's interest, but not to involve its direct responsibility. Last year I reported upon the establishment, under the initiative of the officers of ECPD and after consultation with the secretaries of engineering bodies concerned, of the consultative committee on engineering of the then division of professional and technical employment and training of the War Manpower Commission, of which E. C. Elliott was head. This committee was to be a body to which Doctor Elliott's division could turn for counsel in connection with problems of engineering man power in the war effort, or which could, on its own initiative submit recommendations on behalf of the engineering profession. The committee proceeded promptly to deal with Doctor Elliott, whose purview at that time encompassed substantially all matters of engineering man power in the war effort, and with whom the committee's recommendations had great weight.

"Then, before significant results were accomplished unfortunate changes occurred in the War Manpower Commission. After "employment" was taken out of the division referred to and after the later resignation of Doctor Elliott, and also in view of the fact that the several engineering societies were independently sending recommendations to government agencies concerning professional engineering man power, it was clear to the consultative committee that its status was confused and ineffective and that a clarification should be sought if the committee was to continue. The committee took action to this end on May 18 1943, and requested on the one side that the boards of the engineering societies concerned authorize the committee to make recommendations in their behalf with the understanding that no recommendation would be made that did not have the unanimous approval of the societies concerned; and on the other side, that the War Manpower Commission change the status of the committee so that it would report not to a division or bureau representing only one phase of the general problem of engineering man power in the war effort, but to an office whose purview would encompass any matters about which the committee was likely to have a recommendation.

"At long last I am now in position to report that on the engineering side the proposal has been approved by the boards of the AIEE, ASME, AIME, AIChE, IRE, and SPEE. The ASCE and SAE have not approved. On he side of the War Manpower Commission I am pleased to report that I received only this week a letter notifying me informally that agreement had been reached as to the status of the consultative committee on engineering and that it would report to the chairman of the WMC committee on professional and technical personnel and service (a committee to co-ordinate the work of the several agencies within the WMC in connection with these matters); also that I would receive formal notification within a few days from the office of the executive director of the WMC. Thus the machinery is established for effective communication of counsel from the engineering profession to the WMC in connection with problems of professional engineering man power in the war effort."

The remainder of Chairman Doherty's report reviewed and commented on the work of the ECPD committees during the year. Abstracts of the reports of the four standing committees and of the committees on ethics and on employment conditions for engineers (formerly unionism) follow.

ECPD Committee Reports

STUDENT SELECTION AND GUIDANCE

As in former years, reported Chairman A. R. Cullimore, president, Newark (N. J.) College of Engineering, the ECPD committee on student selection and guidance has concerned itself with two major projects: Counseling and guidance of high-school students, and application of educational measurement for the selection and guidance of beginning students.

The counseling and guidance of high-school students with respect to engineering,

which involves acquainting prospective college students with the nature, requirements, and responsibilities of the profession, has met with special difficulties this year because of the problems posed and questions raised by Selective Service and the various training programs of the Armed Forces. However, the subcommittee in charge of this project prepared and circulated to high schools throughout the United States and to other interested persons digests of material concerning the most significant developments (Selective Service directives, reports of American Council on Education, and the like). Distribution of the booklet, "Engineering as a Career," was continued.

The committee's second project involves the design of tests to determine the probability of a prospective student's completing satisfactorily an engineering curriculum and a plan to determine the validity of such tests. The project has developed into a co-operative program sponsored jointly by the Society for the Promotion of Engineering Education, the Carnegie Foundation for the advancement of Teaching, and ECPD. A battery of tests devised by Albert B. Crawford, department of personnel study, Yale University, New Haven, Conn., has been given to entering freshmen students in a group of representative institutions, and at the end of the freshman year grades were secured for 1,600 individuals who had taken the tests. The results are now being correlated and analyzed.

ENGINEERING SCHOOLS

Believing that engineering colleges cannot be fairly judged while operating under war conditions, the ECPD committee on engineering schools has curtailed its inspections of curricula during the past year, reported Chairman D. B. Prentice, president, Rose Polytechnic Institute, Terre Haute, Ind. A few inspections, however, were necessary in order to complete studies already begun or to prevent injustices to certain institutions. Curricula at eight colleges were investigated, and special consideration was given to 11 curricula at other institutions. The temporary extension of provisional accrediting of 34 curricula at 14 schools is recommended, because it seems to the committee that these colleges are maintaining standards as well as can be expected under present difficulties. This recommendation was approved by the council at the 1943 annual meeting.

In regard to the postwar accrediting program, the committee is continuing to give attention to plans for the reappraisal of all accredited curricula within a reasonable period after the cessation of hostilities. Consideration also is being given to the possible future need for a review of the present accrediting policy and procedure.

In spite of war responsibilities, the committee's subcommittee on technical institutes is continuing its study of technical training of post-high-school but less than professional-engineering level. In addition to courses of the EMSWT (engineering, management, and science war training) type, endowed technical institutes, junior colleges, industrial technical institutes, evening schools of degree-granting colleges, and correspondence courses are being studied.

The committee on engineering schools, Chairman Prentice concluded, is fully aware of the problems confronting technological schools now and the difficulties to be faced in the postwar years. It is taking every precaution it believes feasible to help engineering colleges to maintain and protect scholastic standards.

PROFESSIONAL TRAINING

The "Manual for Junior Engineers," publication of which was authorized last year, received first attention of the ECPD committee on professional training, declared Chairman E. S. Lee (F '30), engineer, General Electric Company, Schenectady, N. Y. Obtaining an author was the main objective of the committee. The committee is most happy to report that W. E. Wickenden has accepted the authorship of the manual and is now writing it.

To keep complete the "General Reading List for Junior Engineers," the junior committee has planned for evaluation of old and new material by having junior groups read the various available books and report on same.

PROFESSIONAL RECOGNITION

Initiation of a co-operative program with a newly appointed committee of the Society for the Promotion of Engineering Education was reported by Chairman C. F. Scott (HM '29), professor emeritus of electrical engineering, Yale University, New Haven, Conn., to be the year's notable achievement of the ECPD committee on professional recognition. Present co-operative effort of the two groups is directed toward determining the most effective use of "The Second Mile," by W. E. Wickenden, in promoting professional attitudes in young engineers. "The Second Mile" was first published in the journals of three of the constituent societies (*EE, May '42, pp. 242-7*); since then nearly 20,000 reprints have been distributed by ECPD, principally through societies and schools.

"How to help in promulgating professional attitudes is a baffling problem," the report concludes. "There is no simple rule or formula for creating an interest and an attitude that will be self-propelling in personal development. The student may resent condescending kindergarten advice from teachers or engineers in practice but be receptive to information and experience and counsel that shows what to do and why. There is need for judgment, ingenuity, tact, and skill, and for a wholesome and invigorating environment.

"Along the 'Second Mile' are thought-provoking paragraphs which invite detours of exploration; articles in the society journals give 'something to think about'; much news in the public press has an engineering background or implication—often to be read between the lines.

"From all this there may evolve among young engineers a common ideal and a common purpose supplementing a common method and a common attitude of mind, which may transcend technical differentiation and lead to a new professional consciousness imbued by the spirit of the engineer. Such should be the basis of a 'profession' into which 'recognition' will have a new significance. Present confusion is the present stage in the evolution of engineering as a profession. We plan for the future."

The report was prefaced by a historical outline of the evolution of ECPD, with particular reference to the contributions of the late Conrad Lauer (*EE, Oct. '43, p. 466*) one of the originators of ECPD and early chairman of the committee on professional recognition.

PRINCIPLES OF ENGINEERING ETHICS

Three of the constituent societies have approved, with modifications in phraseology and arrangement, the proposed canons of ethics formulated by the ECPD committee on principles of engineering ethics, reported Chairman D. C. Jackson (F '12) professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass. Two of the other societies have made reports which are somewhat interdestructive. Four societies have not yet reported their actions. In the meantime, one well-organized local society has adopted the canons for its own use.

The committee plans to examine and correlate all recommendations received from the constituent societies and to make a final report on the canons of ethics to the 1944 annual meeting of ECPD.

EMPLOYMENT CONDITIONS FOR ENGINEERS

V. T. Boughton, chairman of the ECPD committee on employment conditions for engineers (formerly unionism), newly appointed in March 1943, reported briefly for that committee. He said that some factual material on the union movement as it affects engineers had been assembled and is now in the committee's hands for study. His suggestion that the committee make recommendations for the guidance of the constituent societies on the basis of the factual data assembled was approved by the council.

Plans Completed for Local Advancement of ECPD Aims

Provisions for furthering the objectives of Engineers' Council for Professional Development at the "level of the individual" were completed at the recent 11th annual ECPD meeting, with authorization of the publication of a booklet entitled "Will You Help?" The booklet will outline how existing local organization units of the constituent societies can be brought together for joint action on ECPD objectives, under the general inspiration and guidance of ECPD's four standing committees.

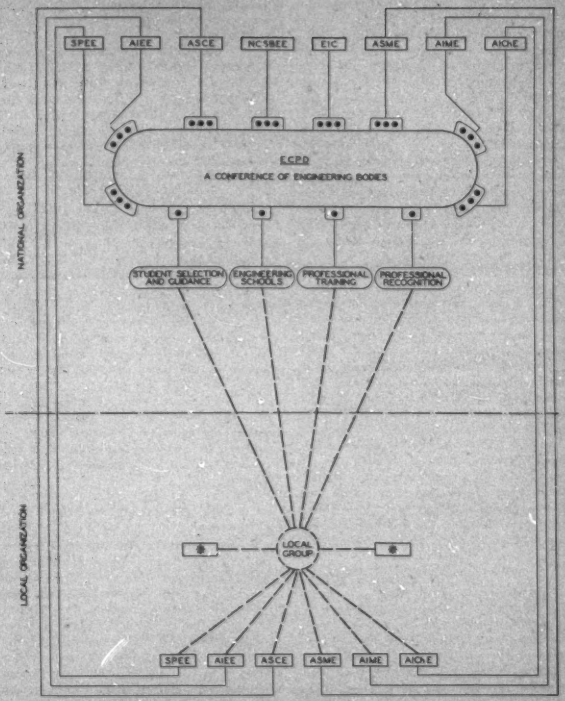
The plan was formulated and initially proposed by AIEE representative J. F. Fairman (F '35) assistant vice-president, Consolidated Edison Company of New York, N. Y. It was approved by ECPD at its 1942 annual meeting and has since been approved by the boards of the constituent

societies. The booklet describing the plan is expected to be issued soon and will be announced in *Electrical Engineering* as soon as available.

How the plan will function is illustrated by the accompanying diagram. Existing organizational channels are indicated by solid lines; new channels provided for by the new plan, by dashed lines. In almost every urban and industrial center and on every college campus there are terminal points of the existing channels in the form of local branches, chapters, or sections of the ECPD constituent societies.

The plan is that in such urban or collegiate centers joint groups be organized to work in the local field on the immediate objectives of ECPD under the general inspiration and guidance of ECPD's four standing committees. If the plan were carried out, the existing channels from each of the national headquarters of the participating bodies to the local units of those societies would be utilized more effectively for the flow both ways, between the council or its committees and the local joint group, of information and inspiration. It is a part of the plan that the local groups enter into direct correspondence with the standing committees of ECPD in order mutually to take advantage of the inspiration, enthusiasm, and experience of individuals working locally and nationally in corresponding fields. Thus, each local group would feel assured that it had the approval of the national body for active participation in the joint programs represented by ECPD. Thus, the approved policies and programs of the council and its committees could find effective national expression *at the level of the individual engineer*.

Suggestions as to where and how to begin will be included in the forthcoming booklet, but in general the best procedures for any specific locality will depend on local conditions, opportunities, and requirements. Committees of ECPD will gladly give assistance by answering questions, supplying information as to the experiences of other local groups, and making suggestions based on their observations. Inquiries may be addressed to Engineers' Council for Professional Development, 29 West 39th Street, New York 18, N. Y.



Outline diagram illustrating plan for establishing local joint groups for furthering ECPD objectives

This diagram relates only to conditions in the United States
—— Existing organizations and lines of communication
- - - Proposed organizations and lines of communication
* *Other local engineering societies*

Report to ECPD by AIEE Representatives

"Although the war has been a disturbing factor in every field of endeavor, yet if one can take the time to inquire, he frequently finds encouraging evidences of activity continuing in spite of that handicap," stated J. F. Fairman (F '35) in presenting the report of the AIEE representatives to the annual meeting of ECPD. "For example, in New York City the work on student guidance, sponsored by the metropolitan chapters of the participating bodies, is going on much as usual, even though an extra burden is imposed on the remaining counselors. Reports on this activity in other cities by delegates to last summer's national technical meeting of the AIEE confirm one's belief that the situation in New York City is not unique. This one inquiry and these reports are the sole basis for the optimistic generalization that the Institute has done, during the past year, as much as usual, or at least as much as could reasonably be expected under present conditions, to further the objectives of ECPD.

"In last year's report, mention was made of the groundwork laid for active encouragement of the Institute's local Sections to establish or to continue co-operative efforts with other local engineering groups in the fields of student selection and guidance and of professional training and of the fact that the next steps to be taken by the Institute would be in accord with the action taken by the council on the chairman's proposals for using the existing organization structures to fuller advantage. The Institute was the first of the participating bodies to approve the proposals and the plan set forth in the pamphlet entitled 'Will You Help?' and hopes that this potentially useful tool will shortly be available for distribution. [See item 'Plans Completed for Local Advancement of ECPD Aims.'] The Institute's representatives still believe, as they stated a year ago, that the greatest progress will be made by the participating bodies acting in concert on matters of this sort. The pamphlet will be tangible evidence of the determination of the participating bodies so to act. Renewed evidence of that determination is sorely needed.

"The 'Manual for Junior Engineers' which is in process of preparation will be another valuable aid in furthering the objectives of ECPD. This manual and similar aid should be made available for distribution and use at the earliest possible moment. It is suggested that consideration be given to the preparation of a suitable

manual or manuals for use in connection with that type of activity among students now being sponsored by the committee on professional recognition.

"If the council expects the local sections of the participating bodies to assist in the furtherance of the program, it must make available to them appropriate material on the subjects and definite suggestions as to how to do the job, and must be prepared to answer questions and supply encouragement. This will not be an easy task, but it will get the results for which the council was organized. In the opinion of this delegation, the council would wisely concentrate on its immediate objective for the present, rather than speculate about any broader objectives . . . ."

Organization of Radio Technical Planning Board and Panels Approved by Sponsors

Final details of over-all organization and selection of the technical panels to carry on the research upon which the recommendations of the Radio Technical Planning Board will be based have been completed by that board. As previously reported (*EE*, June '43, p. 278 and Sept. '43, p. 427) the RTPB will formulate plans, restricted to engineering considerations, for the technical future of the radio industry and services and advise the Government, industry, and the public of its recommendations.

The general plan of organization of RTPB submitted by the Radio Manufacturers' Association and the Institute of Radio Engineers to the initial sponsors was approved unanimously at a meeting September 15, and details of panel organization were decided at a meeting September 29. Initial sponsors of the Board are: American Institute of Electrical Engineers, American Institute of Physics, American Radio Relay League,, FM Broadcasters, Inc., International Association of Chiefs of Police, National Association of Broadcasters, and National Independent Broadcasters. Other sponsors are expected to join RTPB later.

The Board as constituted is composed of one representative for each of its sponsors (nonprofit associations and societies with an important interest in radio which indicate willingness to co-operate in achieving the objectives of the RTPB). Organizations which are interested in the work of the board but do not wish to become sponsors can have representation on the panels or various committees reporting to the panels. Sponsors who contribute, in the first year of operation, a sum of $1,000 are designated contributing sponsors. AIEE is represented on this first board of six contributing sponsors by G. T. Harness (M '36) assistant professor of electrical engineering, Columbia University, New York, N. Y.

An administrative committee selected by the respective contributing sponsors has been made responsible for all RTPB expenditures, approval of the budget, and regulation of other fiscal matters. By means of a monthly report it will account to the sponsors for all expenditures. The chairman of RTPB will also be chairman of the administrative committee while other officers who may be required for effective functioning of the organization will be appointed by the administrative committee but will not have voting power in the decisions of the board. W. R. G. Baker (M '37) has been chosen as first chairman of the board.

The specific paths of investigation to be followed by the RTPB technical panels have been delineated. Each panel will embody its conclusions and recommendations, including all minority opinions, in a report which shall be submitted to the RTPB. Each sponsor's representative will inform his sponsor of the contents of the report to give the latter an opportunity to express its views on the report. If it so wishes, the sponsor may issue a statement to be released with the report. After consideration of the report and of the opinions of the sponsors, the RTPB may release the report with an accompanying statement prepared by the board or return it to the panel for further revision. A report may be returned to the panel only once and must be released on resubmission by the panel. Upon release, copies of each report and any accompanying statements will be transmitted on request to governmental agencies and industrial and professional organizations. Among the 13 panels which have been chosen and the scope of their work defined are:

1. Spectrum Utilization. For the analytical study of the factors pertinent to the most effective use of the transmission medium, A. N. Goldsmith (F '20) chairman.

2. Frequency Allocation. For studying the allocation of frequency bands to services on basis of propagation and equipment characteristics considering military requirements, public interest, and past practices, C. B. Jolliffe (M '34) chairman.

3. High-frequency generation for investigating the present status and probable progress in the development of electronic tubes and the necessary associated equipment for increasing frequency of generation and operation, R. M. Wise, chairman.

Other panels are devoted primarily to the review and development of standards in their respective fields. In this group are panels on: standard broadcasting, H. S. Frazier, chairman; very high-frequency broadcasting, G. E. Gustafson, chairman; television, D. B. Smith (A '35) chairman; facsimile, J. V. L. Hogan (M '30) chairman; radio communication, Haraden Pratt (F '37) chairman; relay system, E. W. Engstrom, chairman; radio range, direction, and recognition, W. P. Hilliard, chairman; aeronautical radio, J. C. Franklin, chairman; industrial, scientific, and medical equipment, C. V. Aggers (A '39) chairman; police emergency services, D. E. Noble (A '32) chairman.

L. C. F. Horle (F '35) manager of the Radio Manufacturers' Association data bureau has been chosen as co-ordinator of the panel organization and work. When the panels are functioning technical experts from all branches of radio will be called upon to assist the board in its investigations. Suggestions and requests for recommendations from branches of the Government or important groups in the radio field will be considered and acted upon by the board.

Final arrangements for co-ordination of RTPB action with that of interested Government agencies, the Board of War Communications, and the Interdepartmental Radio Advisory Committee was left to an informal conference of Government officials and RTPB members and panel chairmen called by J. L. Fly, chairman of the Federal Communications Commission, at Washington, D. C., on November 17. Only questions of procedure between Government agencies and RTPB and not questions of policy for frequency allocation were scheduled for the meeting.

Mentioning various allocation problems which are apparent already, though it is too early to discuss allocation policies, FCC Chairman Fly stressed the pressure of military needs for allocation and also those of the many new radio services in aviation, communications, electronics, frequency modulation, and television. He predicted that radio would go far beyond the very high bands in use before the war and that the spectrum may be extended to entirely new territory, at least to 300,000 kilocycles and later perhaps to 30,000,000

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 20–24, 1944, New York, N. Y.

American Society of Civil Engineers. January 19–21, 1944, New York, N. Y.

American Society of Heating and Ventilating Engineers. 50th annual meeting, January 31–February 2, 1944, New York, N. Y.

American Society of Mechanical Engineers. Spring meeting, April 3–5, 1944, Birmingham, Ala. Semi-annual meeting, June 19–20, 1944, Pittsburgh, Pa.

American Society of Refrigerating Engineers. 39th annual meeting, December 7–9, 1943, Philadelphia, Pa.

Engineering Institute of Canada. Annual meeting, February 1–11, 1944, Quebec, Que.

Exposition of Chemical Industries. December 6, 1943, New York, N. Y.

National Electrical Manufacturers' Association. April 23–7, 1944, Chicago, Ill.

National Fire Protection Association. May 8–11, 1944, Philadelphia, Pa.

kilocycles. Transfer of television to the higher part of the spectrum beyond its prewar position in the 56-megacycle region was another present possibility touched upon Chairman Fly. Moreover he regarded television relays as the medium for national networks and in the future for international television. In his opinion, where wire lines are feasible, it would be economical to use wire facilities and save radio space. The problem of obtaining international standards governing frequencies and manufacture of apparatus which conform to high American engineering levels was also indicated by E. K. Jett, chief engineer of FCC.

Final decisions on allocations for civilian needs, Chairman Fly noted, would be made by the FCC while Government radio needs would be planned by IRAC which includes representatives of the Army, Navy, Coast Guard, Department of Agriculture, Department of Commerce, and other government agencies. IRAC chairman is FCC Commissioner T. A. M. Craven.

WPB and WMC Co-ordinate Production Needs and Man-Power Resources

A basic "urgency" plan to integrate production needs with man-power resources wherever and whenever conditions of urgency may develop any place in the United States have been announced by the War Production Board and the War Manpower Commission.

The plan, based on the pattern established by the Committee of War Mobilization in September, provides for establishment of two committees in any selected "urgency" labor-shortage area:

1. An area production urgency committee, primarily under the control of the WPB, determines which production in the area is of most importance. This will usually be done on a plant-by-plant basis.

2. An area man-power priorities committee, primarily under the control of the WMC, advises the United States Employment Service to allot man power from the scarce supply to those plants where it will have the greatest impact on the war effort.

PRODUCTION URGENCY COMMITTEES

Wade T. Childress has been appointed deputy vice-chairman to handle area production urgency operations.

In each critical area a committee will be established under the chairmanship of a WPB representative and will include representatives of the WMC, War and Navy Departments, Maritime Commission, War Food Administration, Army Air Forces, and such other agencies as may be invited to participate when their particular problems are involved.

Where the interests of the Smaller War Plants Corporation are concerned, the chairman of each production urgency committee will seek the views of that agency and invite its representative to attend committee meetings dealing with that corporation's problems.

No new contracts or renewals of contracts which will aggravate the existing situation will be placed in a critical area except in those cases where for technical or strategical reasons the production executive committee decides otherwise. Where this occurs, the procurement agency involved will be expected to withdraw an equivalent amount of existing work so that the total man-power demand is not increased.

MAN-POWER PRIORITIES COMMITTEES

Area man-power priorities committees shall consist of a representative each of the WMC, WPB, Selective Service System, and Navy and War Departments. If, however, other Government agencies represent important claimants for man power in the area, such as the Office of Defense Transportation, Civil Service Commission, War Food Administration, National Housing Agency, and the Maritime Commission, representatives of such agencies may be added to the committee.

The area man-power priorities committees and the area production urgency committees in critical labor areas will work in close co-operation in order that the labor available may be utilized to best advantage from the point of view of those whose job it is to see that war materials are produced in the shortest possible time with the minimum of confusion.

Production urgency committees and man-power committees have already been set up in San Diego, Los Angeles, and San Francisco, Calif.; Portland, Oreg.; Seattle, Wash.; Akron, Ohio; Detroit, Mich.; and Hartford, Conn.; and man-power committees are also functioning in Buffalo, N. Y., and Louisville, Ky.

The plan will be extended from time to time to other areas. An important phase of the plan is that the area involved will be given almost entire responsibility for solving its problem.

WAR PROGRAM . . .

Navy Bulletin Lists Specialists Needed

The current bulletin, covering the special procurement programs in effect for the Navy, lists many opportunities for specialists with a record of successful training and experience in various fields. Although applicants for a commission or warrant must pass a rigid physical examination, defects which are not organic in nature and which are not likely to interfere with the performance of the specified duties entailed by the programs listed, may be waived by the Navy Department. While the age limits are not inflexible, those outside the age ranges must have exceptional qualifications. Except where otherwise indicated a college degree or years of successful experience is required. The following are among the programs listed:

S.P. 110-43 Production Expediters. Age 30 to 50. To expedite production in plants manufacturing products under navy contracts, with a view to breaking bottlenecks. Candidates should be electrical or mechanical engineers who have specialized in one of the following fields: industrial engineering, marine engineering, ordnance, or steampower. Eight years' practical experience in any of the above fields will be accepted as a substitute for formal education. It is desirable that candidates have a thorough knowledge of production organization, methods, layout, and machines, and be familiar with production problems peculiar to the manufacture of Diesel engines, or radio and electrical equipment, or machinery, or castings and forgings.

S.P. 111-43 Production Analysts. Age 19 to 50. To analyze production methods and check progress of products manufactured under navy contract with a view to keeping navy products up to scheduled delivery. Candidates should meet one of the following sets of qualifications: electrical or mechanical engineers with four years' experience in industrial sales work or two years' actual production experience; graduates of a recognized school of business administration, experienced in business or industrial organization and management with four years' sales work or two years' production experience.

S.P. 114-43 Inspectors of Machinery. Age 30 to 45. To be assigned in the offices of supervisors of shipbuilding and inspectors of machinery for work necessitated by the control materials plan, progress work, and general expediting and administrative work. Should have had experience in a responsible position in the purchasing and procurement of materials in the purchasing departments of contractors and manufacturers covering the following fields: building trades, durable goods industries, steel products, automotive manufacturing, refrigerators, and air conditioning. Should have had executive experience. Salesmen as such are not desired for this program.

S.P. 134-43 Ship Repair. Age 21 to 42. To be assigned to duty in ship repair units for service at advance bases and afloat on repair ships. Candidates who are graduate engineers should have practical experience in at least one of the following categories: Maintenance, repair, or installation of machinery and equipment; maintenance, repair or installation of chemical equipment or experience of a nonresearch character in chemical manufacturing enterprises; Diesel engineering; steel construction, and steam engineering; the field of mechanical engineering (not design engineering); the manufacturing, maintenance, repair or installation of radio, radar, or television equipment; construction, operation, maintenance, or repair of power plants, large motors and generators, industrial electrical equipment.

S.P. 130-43 Naval Academy Instructors. Age 30 to 50. For duty as instructors at the U. S. Naval Academy to teach the following subjects: College algebra, trigonometry (plane and spherical), analytic geometry, calculus, and mechanics; chemistry and physics; radio and electrical engineering; English composition, literature, naval history, European history, government, and American diplomacy, French, Spanish, German, Portuguese, Italian, Russian, and Japanese. Candidates must have at least one degree from an accredited college or university. Must have had at least one year of successful experience in teaching one of the above subjects at a college or university of recognized standing and candidates must be eligible to continue or resume teaching at the same school. Must have sufficient personality, officer-like bearing and appearance to command the respect of the midshipmen.

S.P. 142-43 Antisubmarine. Age 21 to 56. To be assigned duties in connection with the operation and maintenance of underwater ordnance and antisubmarine devices. Candidates must have at least a bachelor's degree in electrical or radio engineering or a degree in physics with a minor in electronics or

radio. It is desirable, but not mandatory that candidates have had experience in radio repair, radio maintenance, radio operation, or have a working knowledge of electrical circuits.

S.P. 143-43 Safety Engineering. Age 30 to 50. To be assigned to duty in all phases of accident prevention in naval shore establishments. Candidates must hold an engineering degree from an accredited college and have had at least five years of practical experience in a responsible position as an industrial safety engineer. In the absence of a degree, candidates must have at least two years of satisfactory college work and ten years of practical experience in industrial safety engineering and have attained a recognised standing in that profession.

A list of Offices of Naval Procurement may be found in the June issue of *Electrical Engineering* page 278.

Use of High-Quality Mica Limited by New WPB Ruling

In view of sharply declining stockpiles of the better qualities of mica, the mica-graphite division of the War Production Board, after consultation with the radio and radar division, acted recently to limit the quantities of this critical material available for production. Beginning in December, the board will undertake to provide manufacturers with amounts of high-grade mica just sufficient to maintain consumption at the average rate maintained during the first nine months of 1943.

Average consumption of good stained mica and better qualities for the first eight months of this year was more than 50,000 pounds in excess of receipts. As a result, government stocks of certain types of mica used in capacitors are at a vanishing point. Industry stocks are reduced, also, in practically all instances, to a minimum working inventory.

The supply of six types of mica, used almost entirely for capacitor films, is shortest. They are: number 4 clear and slightly stained block mica; numbers 5 and $5^1/_2$ fair stained block mica; number $5^1/_2$ good stained block mica; and numbers 5 and $5^1/_2$ fair stained film mica. The insufficiency of these types of mica has compelled the WPB to draw on other types of mica as substitutes. Although the mica-graphite division is not aware of any instance yet in which necessary war production has been delayed because mica could not be provided, it will not be long before suppliers will be unable to meet the demands for mica.

The new policy is not expected to limit mica capacitor production, since the restriction applies only to block mica of good stained quality or better and to film mica of second quality or better. Capacitor manufacturers will have the choice of restricting their production to the number of capacitors that can be made from their allocations of the usually accepted qualities of mica, or of using lower qualities of mica to expand production. The results of the capacitor research project conducted by the National Research Council at Bell Telephone Laboratories, Inc., (*EE, Nov. '43, pp. 511-12*) will be made available to capacitor manufacturers as soon as results have been obtained for each type of mica, to aid them in determining which type of the various lower qualities can be used to best advantage.

The system will be subject to revision quarterly, at which time the ratio of new allocation for capacitor production may be increased or decreased, depending on receipts of mica in the government stockpile during the preceding quarter. Stocks of lower qualities have been accumulating rapidly during the year. On stained quality, the next lower grade to good stained quality, stocks have increased from 370,000 pounds on January 1 to 1,160,000 pounds on August 1, 1943.

Mobile Power Plants Built for Navy

This is one of two mobile railway-car steam-electric power plants with a capacity of 20,000 kw which have been constructed under the direction of the Navy's Bureau of Yards and Docks by the General Electric Company, Schenectady, N. Y. Intended to supply power quickly as it is required by naval shore stations, the units can be hauled at speeds up to 40 miles per hour and their power "put on the line" within 24 hours after they are shunted into a siding. A supply of Bunker C fuel oil sufficient for two hours operation is carried, so that power can be generated even before tank cars are hauled up and connected. The apparatus used in the mobile plants is of the same type proved in service in regular central station and industrial installations throughout the United States. Generation is at 13,800 volts, and transformers are included in the units to provide voltages corresponding to those of the various electric distributing systems which the units will supply

Army and Navy Incentive Films Available to War Plants

War plants wishing to stress to their employees the importance of the worker and his job and his close relationship with the fighting men may secure through the War and Navy Departments industrial incentive films designed especially for war workers and their families.

Included in the subjects are action pictures of the Navy's newest and deadliest antisubmarine weapon, the destroyer escort; landing of the Marines on Guadalcanal; "The Life and Death of the Hornet"; captured German films; landing supplies and evacuating the wounded by Air Transport Command in New Guinea; bombers over North Africa; and the battle of Britain.

These films, which are "restricted" and cannot be viewed in commercial theaters, are made available through a national distribution system of film exchanges in 300 key cities throughout the country. The films are available in both 16-millimeter and 35-millimeter sound-track prints. A nominal fee of one dollar for three reels or less in any one shipment is charged to cover costs of transportation, handling, insurance, and maintenance.

Information on the Navy films may be secured by writing to the chief of the industrial incentive division, Navy Department, 2118 Massachusetts Avenue, Washington, D. C., and information on Army films may be obtained from the chief of the industrial services division, War Department, Bureau of Public Relations, Room 2-*B*-852, the Pentagon, Washington, D. C.

Production of Electric Instruments Increases 4,000 Per Cent

Production of electric indicating and measuring instruments essential to the maintenance of a mechanized war has increased 4,000 per cent since 1940—from 700,000 to 28,000,000 units an-

nually, H. P. Sparks, chairman of the electric-measuring-instrument section, reported at a recent convention of the National Electric Manufacturers Association. Nor will production stop at that level. War Production Board estimates call for an additional 40 per cent increase in 1944 and this scheduled output will bring the level up to 39,000,000 units annually.

Modern warfare requires millions of accurate instruments in order to keep the individual units of the armed forces functioning properly, he explained. A single large bomber may carry as many as 250; one battleship may use 1,000; a submarine mounts 150; and even a tank requires 10. The prominence of the air in modern warfare has brought about a corresponding increase in the need for instruments to guide and control antiaircraft weapons.

To boost production of war-vital combat and industrial instruments, the WPB issued limitation orders, drawn up in co-operation with an NEMA committee, which shut down production of certain nonessential meters and channeled all new instrument orders through a central control for allocation to industry. Standardization and simplification also played major roles in enabling instrument builders to meet their goals. A special war committee on electric indicating instruments was set up by NEMA and the American Standards Association, under the chairmanship of R. B. Shepperd of WPB's simplification bureau. This committee drew up a simplification standard which eliminated as many as 85 per cent of the previously listed variations of instruments.

New Generator Operates at Grand Coulee

Keeping abreast of the steadily mounting power demands of the war industries of the Pacific Northwest, the Bureau of Reclamation has put into commercial production at Grand Coulee Dam another generator rated at more than 100,000 kw, Harold L. Ickes, Secretary of the Interior, announced recently.

According to Secretary Ickes, "the power installed at Grand Coulee during the two years since the first large generator was put into service and the installations at Bonneville Dam farther down the Columbia River were made has met a definite war need and has been responsible in a large measure for the establishment of major war factories in the Pacific Northwest."

In this time the Bureau has made available for war production in the West more than 1,000,000 kw of new hydroelectric power with many of the new generators in operation two to five years ahead of schedule.

The latest addition at Grand Coulee brings the installed capacity of the plant to over 700,000 kw, making it third largest in the United States and fourth largest in the world. The present capacity at the dam is surpassed in the United States only by Boulder Dam power plant and by a steam plant serving the New York metropolitan area. Moreover, with the new installation the rated capacity of the Bureau of Reclamation's 30 power plants in 11 western States passes 2,000,000 kw—equivalent to the total capacity of all public utilities in the 11 far western States in 1920 and nearly as much as that of all plants in the United States when federal reclamation was established in 1902.

WPB Publishes Salvage Manual

The first comprehensive practical manual on industrial salvage ever prepared, "Salvage Manual for Industry," recently published by the technical service section, industrial salvage branch, salvage division of the War Production Board, is now being distributed to industry. There are chapters on organizing and planning the salvage department, administrative factors, methods of handling metal scrap, nonmetallic waste, case histories demonstrating exemplary practice, and practical hints for handling specific waste materials.

The well-illustrated volume was prepared and edited by an editorial board of practical industrial salvage engineers and business paper editors comprising the following:

Editor—Robinson D. Bullard of The Bullard Company, and Fred P. Peters of *Metals and Alloys*

Associate editors—H. E. Blank, Jr., of *Modern Industry*, Arthur M. Perrin of National Conveyors Company, E. J. Tangerman of McGraw-Hill Publishing Company, and R. A. Wheeler of The International Nickel Company, Inc.

Managing editor—John O. Emerson of the industrial salvage branch, WPB

Assisting the editors either with direct contributions or advice was a corps of some 40 engineering or salvage experts. No effort has been spared to cover every possible phase of practical industrial salvage operations and to present the most reliable and authoritative information about them. The book may be secured from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 50 cents per copy.

High-Speed Camera Uncovers Split-Second Mechanical Action

A speed of 8,000 frames or exposures per second is attained with the Fastax camera developed since the war by Bell Telephone Laboratories, Inc., as a research tool. Imperfections in equipment hitherto undetectable are exposed by the great speed of the new camera. Either 8-millimeter or 16-millimeter film may be employed in the camera and it is adaptable to both black and white and color photography and to the photography of self-luminous objects. The intensity of light required for the extra-high-speed pictures is obtained by stepping up the voltage for high-intensity lamp filaments to within a few degrees of their melting temperatures. Although its exposure rate is twice as fast, the Fastax camera resembles in other ways the high-speed camera described in *Electrical Engineering*, November 1940, pages 448–50. Its film speed of from 3 to nearly 70 miles an hour and the continuous film-drive mechanism are the same. Exposure of successive frames in both cameras is accomplished by a revolving prism, and images and film are synchronized as they pass the film gate during the exposure period.

Most of the work being done with the new camera involves secret war projects. It has also been used to photograph action of the vocal chords and to show the explosive short-circuiting of wires carrying heavy currents. It has revealed a cause of imperfection in telephone equipment by showing that the movable part of signal-relay devices was rebounding after the initial contact, and that this was causing extra or false signals in the equipment.

United Nations' Service Reviews Postwar Planning. Part X of Research and Postwar has been issued by the United Nations Information Service, 610 Park Avenue, New York 20, N. Y. The survey is published in two sections—one listing the agencies in the United States and Great Britain which are devoted to postwar planning and the other containing an up-to-date bibliography on the subject. The location, officers, sponsors, background and activities, and publications, if any, are given for each organization. The bibliography is divided into three periods: war, immediate postwar, and reconstruction. The literature pertaining to the periods is arranged under headings denoting the problems peculiar to each. Each section of the survey is priced at 75 cents.

JOINT ACTIVITIES

American Standard for Fixed Composition Resistors Approved

A new American War Standard *C* 75.7, Fixed Composition Resistors, for component parts for military radio and electronic equipment, being developed at the request of the War Production Board, with the co-operation of the War and Navy Departments and the radio industry, has been approved for use by the United States Signal Corps and the United States Navy, Bureau of Ships, radio division, for use in procuring resistors for radio and electronic equipment.

The specification covers fixed composition resistors suitable for use in all nonspecialized applications, in communications and electronic equipment. Performance requirements, test methods, standard dimensions, standard resistance values, and ratings for these resistors of the quality required by the Armed Forces are

contained in this standard. It is the first time an agreement has been reached between the resistor manufacturer and the resistor user as to just what the performance of general-purpose "garden-variety" fixed composition resistors should be. It is expected that this Standard will be used as a guide in the preparation of new manufacturing facilities which are now being expanded because of a service shortage of resistor parts.

The committee which prepared the Standard was headed by F. K. Priebe, Signal Corps Laboratory, Fort Monmouth, N. J., and included representatives from industry and the United States Army and Navy. The Standard may be obtained without charge for procurement purposes only from the government agency concerned. It may be obtained for 60 cents from ASA, 29 West 39th Street, New York 18, N. Y.

ASA Observes Silver Anniversary

American Standards Association will observe the 25th anniversary of its founding at its annual luncheon meeting December 10, in the Hotel Roosevelt, New York, N. Y. The association, started as a result of the production problems of the last war, has completed more than 40 emergency jobs for the armed services and industry in the past year and is engaged in many others.

Clifton E. Mack, director of procurement, United States Treasury, will discuss the use of standards for bringing government requirements more nearly in line as a part of the American industrial system at the meeting December 10. Mr. Mack is in charge of all government lend-lease purchasing. R. E. Zimmerman, president of ASA, will talk on postwar changes and developments, and H. S. Osborne (F '21) chairman of the Standards Council, will report on the year's work. In commemoration of its silver anniversary, ASA is inviting all who wish to attend the annual meeting, whether they are members of the organization or not. Information about the meeting may be obtained from ASA, 29 West 39th Street, New York 18, N. Y.

EDUCATION • • •

Wayne University Acquires Hooker Scientific Library

The Kresge Foundation has granted to Wayne University the sum of $100,000 for the establishment there of a scientific library, announces David D. Henry, executive vice-president of the university. The grant, together with an equal amount contributed by interested organizations and individuals, will be used to purchase and modernize the Hooker Scientific Library, now located at Central College, Fayette, Mo. The modernized collection will be known as the Kresge-Hooker Scientific Library.

According to Doctor Whitehouse, "The Hooker Library, built upon the basic collection of the noted scientist, Samuel C. Hooker, is not only recognized as one of the world's most complete collections of books and journals on chemistry, but is also of great value to the related sciences and to engineering. It is widely used by research scientists in all parts of the United States who utilize the reference and translation services supported by the Friends of the Hooker Scientific Library."

The Kresge Foundation funds will be handled through the Wayne University Foundation, according to Gordon W. Kingsbury, secretary of that organization.

OTHER SOCIETIES •

NEMA Issues New Standard. The new Feeder-Voltage-Regulator Standards, publication 43-86, recently issued by the National Electrical Manufacturers Association, comprises all the standards of national character pertinent to feeder and step-type voltage regulators in a single 28-page pamphlet. Among the subjects treated are: The effect of altitude on temperature rise, rating, grounding, insulating materials, tests, performance specifications, bushing characteristics, guides for loading, efficiencies and losses, and terminal markings. The pamphlet is completed with a section devoted to the definition of terms. Copies may be obtained from NEMA headquarters, 155 East 44th St., New York, N. Y., at 75 cents a copy.

U. S. Committee of ICI Re-elects Officers

At the annual meeting of the United States national committee of the International Commission on Illumination November 10, 1943, the following officers were re-elected:

President—Preston S. Millar (M '13) of Electrical Testing Laboratories, Inc.

Vice-president—F. C. Breckenridge of National Bureau of Standards.

Secretary-treasurer—G. H. Stickney (F '24) consulting engineer.

Executive Secretary—A. A. Brainerd of Philadelphia Electric Company.

This United States committee has published an all-English version of the proceedings of the international meeting held in Holland in 1939. Copies, recently made available, may be obtained through the executive secretary. These record the latest stage of development of lighting throughout the world up to the beginning of the war and have reference value for people in the lighting industry.

The United States committee is engaged in cultivating, in behalf of the international body, arrangements for technical interchange of lighting information with leading engineers in the other Americas.

Industrial Safety Engineering Division of NSC Reorganized

The National Safety Council has reorganized the activities of its industrial safety engineering division to provide more practical and specific assistance for accident and health problems in modern industry, according to Walter S. Paine, vice-president for industrial safety.

The new plan makes use of the industrial membership sections as centers for the accumulation and distribution of all safety information in their respective fields. Such information, in the form of safe practices pamphlets, industrial data sheets, engineering summaries, safety instruction cards, posters, and other technical materials must be kept up to date and must be designed to fit the exact needs of those who will use it.

Each safety engineer on the staff has been appointed as staff contact for one or more of the industrial sections, in accordance with his experience and knowledge.

Division engineers and the sections to which they have been assigned are:

J. M. Roche, director of the industrial division; J. C. Stennett, assistant director of the industrial division, secretary of the American Society of Safety Engineers, and contact man for the aircraft manufacturing industries and air-transport companies; C. D. Bridges, paper, pulp, and petroleum industries; F. E. Frazier, construction, mining, cement, and quarry industries; A. M. Baltzar, food, meat-packing, and textile industries; E. M. Jasper, metals industries and public utilities; B. A. Grainger, automotive, machine-shop, and marine industries, and power-press problems; and F. Van Atta, chemical, rubber, and refrigerator industries.

In the future, additional engineers will be added to the staff—one to have full-time assignment to problems in the mining industry, another to handle railroad safety problems, and a third who will act on assignments relating to industry generally.

IRE Elects 1944 Officers

Election of Hubert M. Turner (M '20) associate professor of electrical engineering, Yale University, New Haven, Conn., as president of the Institute of Radio Engineers, was announced recently by the board of directors of that organization.

Also elected were R. A. Hackbusch, vice-president in charge of radio, Research Enterprises, Ltd., Leaside, Ont., as vice-president of the institute; and for three-year terms as directors: R. F. Guy, engineer, National Broadcasting Company, New York, N. Y., L. C. F. Horle (F '35) consulting engineer, New York, N. Y., and W. C. White (M '30) director of the electronic laboratory, General Electric Company, Schenectady, N. Y.

AIME Elects Officers for 1944

Election of C. A. Fulton, president of the Southern Phosphate Corporation, Baltimore, Md., as 61st president of the American Institute of Mining and Metallurgical Engineers was announced recently by A. B. Parsons, executive secretary of AIME. Other officers elected were: Vice-presidents, J. L. Christie, metallurgist and manager, Handy and Harmon, Bridgeport, Conn. and J. R. Van Pelt, Jr., geologist and technical director, Museum of Science and Industry, Chicago, Ill.; and six directors, M. H. Fies, mining engineer and vice-president in charge of mining division, De Bardeleben Coal Corporation, Birmingham, Ala.; H. T. Hamilton, assistant to the president, New York Trust Company, New York, N. Y.; J. C. Kinnear, mining and metallurgical engineer, general manager, Nevada Mines Division, Kennecott Copper Corporation, McGill, Nev.; W. E. Pratt, geologist, vice-president, Standard Oil Company of New Jersey, New York, N. Y.; J. R. Suman, vice-president in charge of production, Humble Oil and Refining Company, Houston, Tex.; and R. W. Thomas, general manager, Nevada ConsolidatedCopperCorporation,Ray,Ariz.

late for the advice to influence governmental policies.

Any such organization, to be effective in its ministry, must be active and not passive. Engineers are also members of the body politic and if they expect to influence governmental action in other fields than mere planning of engineering structures, they must use not only engineering technique, but the technique that will be most effective. The use of this effective technique the engineering societies have not only deprecated, but eschewed for a long time.

C. M. JANSKY (F '32)

(Professor emeritus of electrical engineering, University of Wisconsin, Madison)

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Planning for Things to Come

To the Editor:

"It is hardly lack of due proce s for the government to regulate that which it subsidizes."

United States Supreme Court re Wickard vs. Filburn

I have just finished reading the Institute's past-president's most interesting and thought-provoking discourse on "Planning for Things to Come" (*Electrical Engineering*, August 1943, pages 333–337), and I would like to add a mite to the discussion.

Yes, there must be planning for things to come as there always has been, even though no one seems to know what things will come. It seems to me, however, that Doctor Osborne neglected to mention the most limiting and controlling factor in all such planning. That factor is the future relation of the Federal Government to private or free enterprise. The crucial question that must be answered before any effective plans can be formulated is, will business and industry be permitted to plan freely and to execute the plans formulated, or will government agencies control. If the latter is the case, then the kind of planning suggested by Doctor Osborne will have little influence on "things to come." For example, the engineers of the American Telephone and Telegraph Company will undoubtedly make plans for improving, increasing, and enhancing the value of the services of the company's communication systems, but it cannot cooperate with the Western Union Telegraph Company without running afoul of the national antitrust and monopoly laws. This, however, is only an example.

Furthermore, if the government subsidizes industry and business, either directly or indirectly, it will control them and direct their activities in accordance with the declaration of the Supreme Court cited above, and the planning for "things to come" will be done by governmental agencies, and it will be a waste of effort to make other plans. Likewise, if the government continues to compete with business and industry which provide the taxes to pay for such competition, private enterprise will gradually decline and finally fade away and die. The evidence in support of these propositions is all around us.

If, therefore, the engineers hope to have controlling influence on "things to come," their first efforts should be devoted to the making of plans for freeing enterprise from the socialistic controls of the government. Obviously the AIEE board of directors have already recognized the necessity for such efforts by passing resolutions against the adoption of the Kilgore and Patman bills. That is a step in the right direction, but resolutions alone are not enough. Resolutions must be followed up by action, not by the board of directors alone, but by the individual members of the Institute and other like-minded persons.

Doctor Osborne further suggests the affiliation of all engineering societies and organizations into some form of a super organization whose duties will be to place "emphasis on ministry to the people rather than on direct services to its members" and "to give advice to the numerous agencies of government on the engineering phases of public questions." That was the objective of the now defunct American Engineering Council. Its failure was not due to defects in technical organization but to its inactivity. It acted on the assumption that its ministry to both the engineers and society would be most effective if it waited to be asked by government agencies for advice "on the engineering phases of public questions," but such questions seldom came, and when they did come it was too

NEW BOOKS . . .

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; those and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Aircraft Year Book for 1943. 25th annual edition. Howard Mingos, editor. Aeronautical Chamber of Commerce of America, Shoreham Building, Washington, D. C.; distributors, Lanciar Publishers, New York, N. Y., 1943. 728 pages, illustrations, etc., 9 by 5½ inches, cloth, $5. (ESL.)

As in previous editions this 1943 publication presents a record of events and developments in the aviation field during the past year. It covers the war in the air, the United States Army and Navy air forces, the Civil Air Patrol, air-force training, governmental activities, and the air lines in war transport. The latter part of the book is devoted to aircraft designs, directories of manufacturers in the field, and statistical information.

Manual of ASTM Standards on Refractory Materials. Prepared by ASTM Committee C-8 on Refractories. American Society for Testing Materials, 260 S. Broad Street, Philadelphia, Pa., 1943. 201 pages, illustrations, etc., 9 by 6 inches, paper, $1.50; cloth, $1.75. (ESL.)

Designed to give all of the ASTM standards on refractory materials—specifications, methods of physical tests, chemical analysis, and definitions—this extensively revised and enlarged publication also includes pertinent data developed by the committee and other supplementary information of service to those concerned with refractories.

Airport Construction and Operation Reference. 1943–44 annual edition. Occidental Publishing Company, Los Angeles and San Francisco, Calif., and New York, N. Y., 1943. 96 pages, illustrations, etc., 12 by 9 inches, cardboard, $2. (ESL.)

In the text of this book the subjects of airport design, seaplane bases, war airfields, airport surfaces, buildings, lighting, communications, and traffic control are presented by useful summaries of practice. In addition there is a buyer's directory of airport-equipment manufacturers and a directory of associations and agencies.

Structures of Metals. By C. S. Barrett. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 567 pages, illustrations, etc., 9 by 6 inches, cloth, $6. (ESL.)

Crystallographic methods for investigating the structure of metals are discussed. The first four chapters explain the fundamentals of crystal lattices and projections and the general principles of the diffraction of X rays from crystals. Chapters 5 to 7 cover the technique of X ray diffraction. The latter half of the book is devoted to the results of research along specific lines of current interest, including a chapter on electron diffraction. The book is intended for graduate courses.

Maximum Utilization of Employed Manpower. (Research Report Series No. 68.) Princeton University, Industrial Relations Section, Princeton, N. J., 1943. 46 pages, 9½ by 6 inches, paper, $1. (ESL.)

This publication constitutes an outline listing a wide range of symptoms or ailments which are likely to accompany or cause underutilization of employed labor. Most of the subheadings, however, indicate positive steps, drawn from widespread company experience, which have proved successful remedies. A detailed bibliography is appended.

Engineering Drawing Problems. By I. N. Carter and H. L. Thompson. International Textbook Company, Scranton, Pa., 1943. 142 pages, plates, etc., 8½ by 12 inches, stiff paper, $2.25. (ESL.)

A carefully selected group of drafting exercises designed to be used with the text, *Engineering Drawing—Practice and Theory*, is presented by the same authors. In addition to the problem plates already made up, there are several blank plates for special work, and a number of sheets of tracing paper are provided for tracing practice.

Circuit Analysis of A-C Power Systems. Volume I. Symmetrical and Related Components. By E. Clarke. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 540 pages, diagrams, etc., 9 by 5½ inches, cloth, $6. (ESL.)

In the two-volume set of which this is the first volume, the methods of solving unbalanced power-system problems by means of components are analyzed and discussed in detail. Volume I deals largely with the determination of currents and voltages of fundamental frequency in power systems, by means of symmetrical and related components, including overhead transmission circuits, transformers, and synchronous machines. The use of equivalent circuits and the solution of practical problems are emphasized.

Electricity and Its Application to Civilian and Military Life. By Charles A. Rinde. Harcourt, Brace and Company, New York, N. Y., and Chicago, Ill., 1943. 466 pages, illustrations, 9½ by 6¾ inches, cloth, $2.50.

This book is organized around the War Department's *Outline, Fundamentals of Electricity (PIT-101)*, but the outline has not been followed slavishly. The book thus provides a broad foundation for the fields of specialization suggested by the various technical and field manuals. Since all the principles underlie equally the civilian and military uses of electricity, both civilian and military applications have been stressed throughout.

Treatment of Experimental Data. By A. G. Worthing and J. Geffner. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 342 pages, illustrations, etc., 9½ by 6 inches, cloth, $4.50. (ESL.)

As an aid to scientists and engineers in presenting experimental data clearly and usefully, this book presents and discusses the following topics: rules for graphing; methods of smoothing and tabulating; a moderately extended treatment of precision indexes; the essentials of correlation; Fourier series and harmonic analysis as a means of representing data; and the use of determinants as a means of simplifying computations.

Structural Frameworks. By C. T. Morris and S. T. Carpenter. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 272 pages, illustrations, etc., 9 by 5½ inches, cloth, $4. (ESL.)

This book, which is intended for advanced students, is concerned with the analysis of some complex problems that arise in the design of buildings and structural frameworks, including industrial buildings and radio and transmission towers. Numerous examples are worked out to illustrate the methods used.

Slide Rule Simplified. By C. O. Harris. American Technical Society, Chicago, Ill., 1943. 250 pages, etc., 8½ by 5½ inches, cloth, $2.50; with slide rule, $3.50 (ESL.)

The practical manipulation of the slide rule is explained in detail. The first eight chapters cover the relatively simple straight arithmetical operations for the beginner. Succeeding chapters deal with the handling of trigonometrical relations and other more complex operations. The logarithmic basis of the functioning of the slide rule is explained for those who are interested.

Metal Forming by Flexible Tools. By C. J. Frey and S. S. Kogut. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1943. 193 pages, illustrations, etc., 9½ by 6 inches, cloth, $3. (ESL.)

The characteristics of the flexible tool, developed and mainly applied in the aircraft industry, to meet the frequent changes in design necessitated by war, are low first cost and rapidity of manufacture, and the ability to adhere to sheet-metal tolerances so as to permit interchangeability. The answer to the need for flexible tooling has been found in the rubber press, the drop hammer, the power brake, the stretch press, and the Anderson method of forming by drawing, described in detail in this book.

Marconi, Pioneer of Radio. By D. Coe. Julian Messner, New York, N. Y., 272 pages, illustrations, etc., 9 by 6 inches, cloth, $2.50. (ESL.)

Marconi's great influence on the development of wireless transmission is told in narrative style. Much biographical detail is included with the character of the man himself emphasized. Important and dramatic incidents connected with Marconi's life and the rise of radio as a useful science increase the interest of the book.

Management of Manpower. By A. S. Knowles and R. D. Thomson. The Macmillan Company, New York, N. Y., 1943. 248 pages, illustrations, etc., 9 by 5½ inches, cloth, $2.25. (ESL.)

The text, part of a larger volume on industrial management, is reproduced for those whose primary attention is devoted to handling workers. It discusses the modern tools and techniques available for the effective and intelligent handling of man-power problems leading toward greater efficiency, higher production, and better co-operation of the workers. Job evaluation and merit rating are emphasized.

General Physics. By O. Blackwood. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 622 pages, illustrations, etc., 8½ by 5½ inches, cloth, $3.75. (ESL.)

The whole field of college physics is covered in this elementary text. The major divisions are: mechanics; molecular physics and heat; vibrations, wave motion, and sound; light; electricity and magnetism; and the new physics. Emphasis is placed on the practical illustration of physical principles by examples from everyday life.

Metallography of Aluminum Alloys. By L. F. Mondolfo. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 351 pages, illustrated, 9 by 5½ inches, cloth, $4.50.

Four main sections of this book cover, respectively: the equilibrium diagram of aluminum alloys; the technique of macro- and microexamination; the normal structure of the commercial alloys of aluminum; the effect of fabricating on the microstructure, with references to macrostructure and actual practices. Since the book is intended for the plant metallurgist rather than the student, no details are given on general metallurgy and metallography. There is a large classified bibliography.

Electronic Interpretations of Organic Chemistry. By A. E. Remick. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 474 pages, illustrated, 9 by 5½ inches, cloth, $4.50. (ESL.)

The main purpose of this book is to show how electronic theories of organic chemistry may be combined with such modern developments in physical chemistry as the quantum-mechanical concept of resonance and the transition-state theory of reaction rates. The work is intended as a review and an advanced textbook in which those developments in the field of physical and theoretical chemistry that seem to offer new and useful methods of attacking the problems of preparative organic chemistry are presented.

Electrical Engineering. By E. M. Strong. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 391 pages, diagrams, etc., 9 by 5½ inches, cloth, $4. (ESL.)

An introductory presentation of basic concepts essential to the clear understanding of electrical-engineering problems. It includes an introduction to alternating current and voltage as part of this basic material. A knowledge of the calculus involved in the explanation is required of the student. Detachable work sheets containing useful graphs are provided at the end of the book.

Blueprint Reading for the Shipbuilding Trades. By A. E. Niederhoff. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 87 pages, illustrations, etc., 11 by 8 inches, cloth, $2. (ESL.)

The fundamentals of blueprint reading necessary for the shipbuilding trades are covered in a simple and concrete manner. Orthographic projection, alphabet of lines, symbols, abbreviations, and ship terms are included. Actual prints used in shipyards mainly for construction of Liberty ships are used as examples.

Introduction to Heat Engines. By E. A. Allcut. University of Toronto Press, Toronto, Ont., Canada, 1943. Paged in sections, illustrated, 9½ by 6 inches, cloth, $2.75. (ESL.)

This book provides a concise interesting introduction to the field of heat engines indicating the existence of the same general scientific principles in all types of heat engines. Each chapter is illustrated by applications to steam engines, turbines, air compressors, and internal-combustion engines, whose similarities as well as differences are pointed out. Chapter four is an excellent brief historical survey.

Organization for Metropolitan Planning. American Society of Planning Officials, Chicago 37, Ill., 1943. 73 pages, illustrated 10 by 7 inches, paper, $1. (ESL.)

This pamphlet contains the four prize-winning essays in a national competition for the best proposal for the organization and operation of a regional council in a metropolitan area. The essays are presented to stimulate thinking upon a problem that is becoming increasingly acute as the tax base moves out from our cities, while these are called upon to provide social services upon an increasing scale.

Aeroplane Production Yearbook and Manual I. Edited by G. W. Williamson, foreword by Sir C. Bruce-Gardner. Paul Elek Ltd., Africa House, Kingsway, London, W.C.2, England, 1943. 564 pages, illustrated, 8½ by 5½ inches, linen, 40s.10d., 41s.6d. abroad. (ESL.)

The purpose of this volume is to provide information regarding production methods in a compact and accessible form. The use and treatment of aircraft materials are described, general and specialized manufacturing processes are explained, and the construction and characteristics of the varied types of airplane equipment are discussed. There is a large bibliography which includes numerous abstracts.

Practical Radio Communication. By A. R. Nilson and J. L. Hornung. Second edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 927 pages, illustrated, 9 by 5½ inches, Fabrikoid, $6. (ESL.)

Basic radio principles are concentrated in the first eight chapters of this comprehensive work. The practical application of these principles to aviation radio, broadcasting, and marine radio follow in the order given. Important additions in this edition include material on amplifiers, the cathode-ray oscilloscope, antenna arrays, ultrahigh-frequency theory and practice, frequency modulation, and direction finders.

Tungsten. American Chemical Society Monograph 94. By K. C. Li and C. Y. Wang. Reinhold Publishing Corporation, New York, N. Y., 1943. 325 pages, illustrated, 9½ by 6 inches, cloth, $7. (ESL.)

This volume, written by the leading authority on tungsten, covers its subject thoroughly. The geology of the ore deposits, ore dressing, metallurgy, and chemistry are discussed. A chapter is devoted to analysis. Further chapters consider the industrial uses of tungsten, substitutes for tungsten in steel alloys, and the economics of the tungsten industry. The chapters have useful bibliographies.

Hyper- and Ultrahigh-Frequency Engineering. By R. I. Sarbacher and W. A. Edson. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 644 pages, illustrated, 9 by 5½ inches, cloth, $5.50. (ESL.)

All phases of hyperfrequency engineering are discussed in considerable detail, including the generation, transmission, and reception of quasi-optical waves. Following the basic electromagnetic theory are chapters on wave guides, transmission-line theory, cavity resonators, horns and reflectors, vacuum-tube behavior, and applications of tubes. A large bibliography is included.

The J. & P. Switchgear Book. Volume 2. By R. T. Lythall. First edition. Johnson and Phillips Ltd., Charlton, London, England, S.E.7, 1943. 227 pages, illustrated, 9 by 6 inches, cloth, 15s. plus postage. (ESL.)

The new volume of this well-known work on switchgear is planned, like the first, to supply practical information for the needs of nonspecialists. Volume 2 supplements volume 1 by covering some items omitted in it and by giving information on later developments.

Planning and Postwar Planning—State Organizations. American Society of Planning Officials, Chicago 37, Ill. 34 pages, manifold copy, 11 by 8½ inches, paper, $1.

This is a directory giving the names of officials and members, and office addresses of these organizations.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

The Financial Record of the Electric Utility Industry 1937–42. Federal Power Commission, Washington, D. C., 10 pages, no charge.

Some Comments on Emergency Electrical Products. Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago 11, Ill., 11 pages.

Pipe and Tube Bending Handbook. Copper and Brass Research Association, 420 Lexington Avenue, New York 17, N. Y., 80 pages.

Fundamentals of Electronic Control for Resistance Welding. Industrial Control Division, General Electric Company, Schenectady, N. Y., 44 pages.

The Story of the Turbine. General Electric Company, Schenectady, N. Y., 24 pages.

Wartime Fires, fourth edition. National Fire Protection Association, 60 Batterymarch Street, Boston 10, Mass., 20 pages, 10 cents.

Safe Streets at Night. Street and Highway Lighting Safety Bureau, 155 East 44th Street, New York, N. Y., 26 pages.

Wartime Lighting and Safety. Street and Highway Lighting Safety Bureau, 155 East 44th Street, New York, N. Y., 26 pages.

Getting Down to Earth on Postwar Work. Corrigan, Osburne and Wells, Inc., Lincoln Building, New York, N. Y., 29 pages.

Radio Broadcasting Postwar. General Electric Company, Schenectady, N. Y., 19 pages.

Typical Residential Electric Bills, Cities of 2,500 Population and More. Federal Power Commission, Washington, D. C., 1943, 87 pages, 25 cents.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1943 Supplement to Electrical Engineering—Transactions Section

Lightning Surges Transferred From One Circuit to Another Through Transformers

P. L. BELLASCHI
FELLOW AIEE

IT is generally recognized that through the medium of transformers surges can be transferred from circuits exposed to lightning to circuits considered otherwise nonexposed. The latter may connect to rotating machines or to industrial apparatus of inherently low-impulse insulation level. On these seemingly nonexposed circuits may be found apparatus of old design which as a rule are even more vulnerable to surges. In these problems the question is to determine

1. The extent apparatus may be endangered.

2. Whether the relative risk incurred weighed against the importance of the installation and the cost of damage, warrants protective equipment.

In each case sound engineering recommendations demand a fairly close estimate of the transferred surges.

In examining cases of this character in addition to published data, the writer has found particularly helpful the results of an investigation at Sharon in 1932–33. Seasoned by experience, these results and the simplified methods derived from them are presented here to assist in a practical way those engaged in this type of protection studies. This contribution should serve besides to call attention again to the vital importance transferred surges may assume under certain conditions.

Paper 43-133, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE national technical meeting, Salt Lake City, Utah, September 2–4, 1943. Manuscript submitted May 13, 1943; made available for printing July 1, 1943.

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The author acknowledges the assistance of R. E. Armington in the preparation of this article.

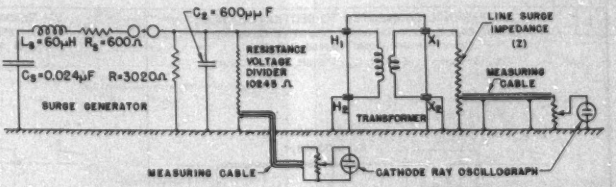
The Nature of the Problem

Contributions on the mechanism governing the transfer of surges through transformers have been reported by various investigators.[1–8] Concurrently, the protection of rotating machines and similar low-impulse-strength apparatus subject to these surges has been discussed.[6–11] Essentially, when a lightning surge is impressed on one winding of a transformer, a surge appears at the terminals of a second winding. The surge thus transferred to other windings and connected circuits consists respectively of an electrostatic component and an electromagnetic component. The electrostatic component results from the capacitance coupling between the windings and to ground (Figure 13), while the electromagnetic component depends on the turn ratio and the short-circuit inductance between the two windings (Figure 15). The terminal conditions naturally contribute also to determine the amplitude, the wave form, and the duration of the surge transferred. Superimposed on these components will be present in lesser or greater amounts the effects due to oscillations from the windings. All these factors will be apparent from the tests and the discussion which follow.

One Series of Tests

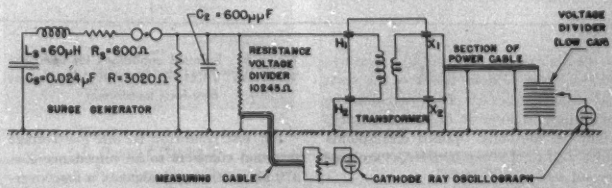
All tests and the corresponding measurements were conducted in the manner illustrated in Figure 1. In this series of tests the transformer is a single-phase two-winding core-form unit, rated at 1,000 kva and 76,210/2,300 volts. The turn ratio is 33.1 to 1. Other characteristics of the transformer are listed in Table I. The terminal arrangements cover a wide range of the practical conditions encountered in service. These are summarized in Figure 2. The voltage applied

Figure 1. Typical arrangements and method of test



A (above). Low-voltage terminal of transformer connected to line

B (below). Low-voltage terminal of transformer connected to section of cable



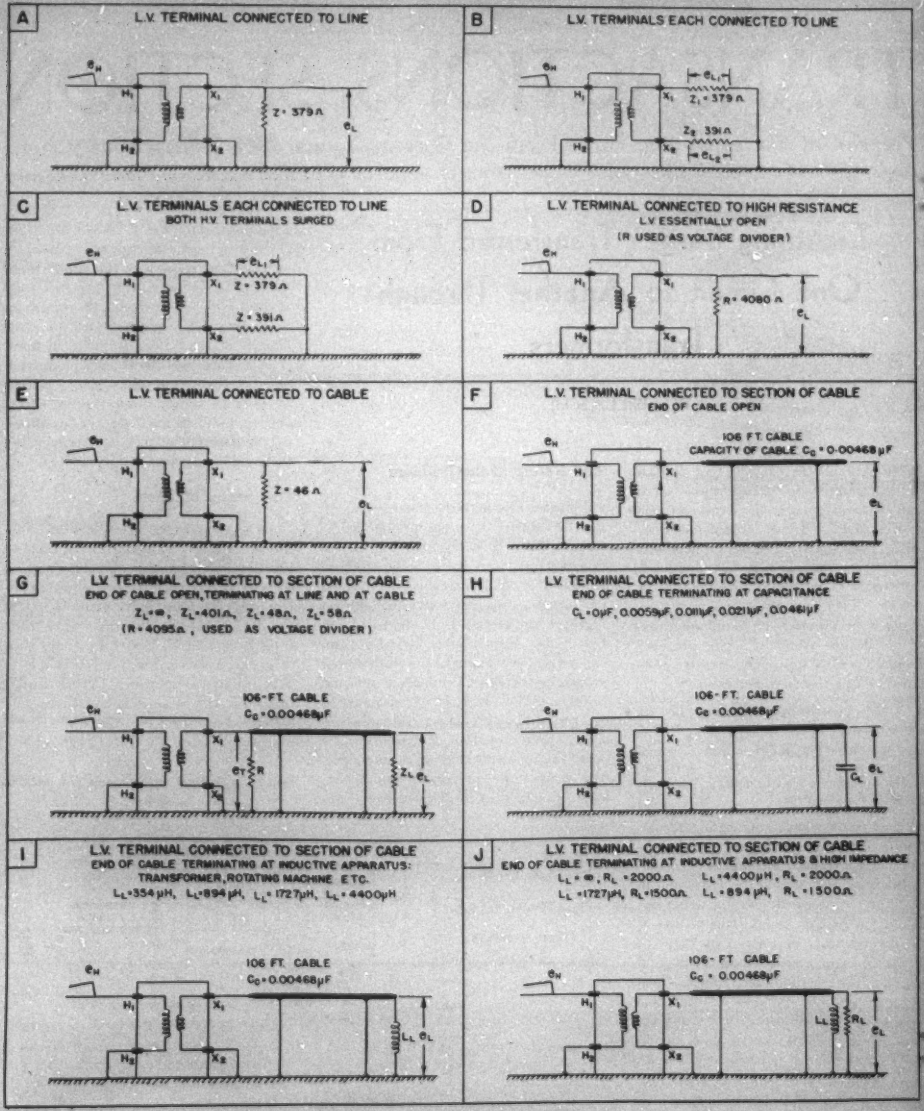

A
L.V. TERMINAL CONNECTED TO LINE
Z = 379 Ω
B
L.V. TERMINALS EACH CONNECTED TO LINE
Z1 = 379 Ω
Z2 391 Ω
C
L.V. TERMINALS EACH CONNECTED TO LINE
BOTH H.V. TERMINALS SURGED
Z = 379 Ω
Z = 391 Ω
D
L.V. TERMINAL CONNECTED TO HIGH RESISTANCE
L.V. ESSENTIALLY OPEN
(R USED AS VOLTAGE DIVIDER)
R = 4080 Ω
E
L.V. TERMINAL CONNECTED TO CABLE
Z = 46 Ω
F
L.V. TERMINAL CONNECTED TO SECTION OF CABLE
END OF CABLE OPEN
106 FT. CABLE
CAPACITY OF CABLE Cc = 0.00468 μF
G
L.V. TERMINAL CONNECTED TO SECTION OF CABLE
END OF CABLE OPEN, TERMINATING AT LINE AND AT CABLE
ZL = ∞, ZL = 401 Ω, ZL = 48 Ω, ZL = 58 Ω
(R = 4095 Ω, USED AS VOLTAGE DIVIDER)
106-FT. CABLE
Cc = 0.00468 μF
H
L.V. TERMINAL CONNECTED TO SECTION OF CABLE
END OF CABLE TERMINATING AT CAPACITANCE
CL = 0 μF, 0.0059 μF, 0.0111 μF, 0.0211 μF, 0.0481 μF
106-FT. CABLE
Cc = 0.00468 μF
I
L.V. TERMINAL CONNECTED TO SECTION OF CABLE
END OF CABLE TERMINATING AT INDUCTIVE APPARATUS:
TRANSFORMER, ROTATING MACHINE ETC.
LL = 354 μH, LL = 894 μH, LL = 1727 μH, LL = 4400 μH
106 FT. CABLE
Cc = 0.00468 μF
J
L.V. TERMINAL CONNECTED TO SECTION OF CABLE
END OF CABLE TERMINATING AT INDUCTIVE APPARATUS & HIGH IMPEDANCE
LL = ∞, RL = 2000 Ω LL = 4400 μH, RL = 2000 Ω
LL = 1727 μH, RL = 1500 Ω LL = 894 μH, RL = 1500 Ω
106-FT. CABLE
Cc = 0.00468 μF

Figure 2. Terminal conditions for tests with 1,000-kva 76,210/2,300-volt single-phase core-form transformer

to the high-voltage winding (e_H) measures 364-kv crest, and in this too the tests have the significance of approaching the conditions of interest in actual service. Likewise, the surge applied corresponds quite well to the standard $1^1/_2 \times 40$-microsecond wave.

For test condition *A*, one low-voltage terminal connects to an impedance $Z = 379$ ohms, the equivalent of a long overhead line. The other terminal goes directly to ground. The surge voltage e_L transferred to the low-voltage terminal and to the line is recorded in Figure 3. In effect it rises to crest in eight microseconds, and recedes on the tail in about the same time as the wave applied. The

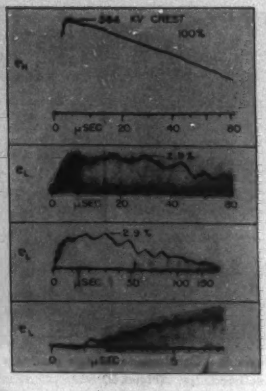
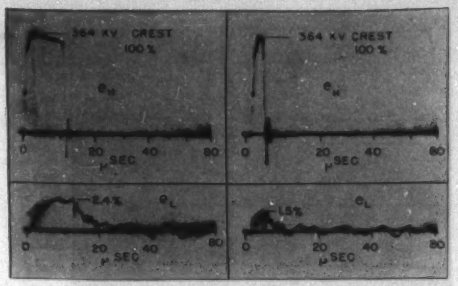


Figure 3. Oscillograms for test condition *A* (Figure 2)

Figure 4. Oscillograms for test condition *A* (Figure 2)



electrostatic component accounts in part for the front. Beyond crest the electromagnetic component plus the superimposed oscillations predominate. The crest value 2.9 per cent corresponds essentially to turn ratio (100 per cent divided by 33.1). Test *A* was repeated with chopped waves applied. From Figure 4, as it should be expected, the surge e_L transferred to the line practically disappears for increasingly shorter impulses e_H.

In test *B*, each of the low-voltage terminals connects to a line impedance. In this case, the electromagnetic component divides about equally between the two lines, as in e_{L_1} and e_{L_2} of Figure 5. Note also the opposite polarity with respect to ground of the two. Only on the low-voltage terminal, physically opposite H_1, does the electrostatic component occur. In test *C*, surge e_H is applied simultaneously to both high-voltage terminals, so that in this case the electromagnetic component in e_L (Figure 5), disappears. Here the electrostatic component (1.3 per cent) is followed by the natural oscillations set up in the winding. In test *D*, the high resistance practically amounts to an open low-voltage terminal. Under this condition, because of the full development of the electrostatic effect and similarly because of the rapid development of the electromagnetic effect, the surge e_L (Figure 5) rises more abruptly and reaches a higher crest (3.7 per cent) than in any of the previous tests. The bottom oscillogram e_L of Figure 5 shows the influence of a long cable. This condition corresponds to *E*. As the result of the low impedance of the cable, the electrostatic effect practically has vanished insofar as appearing at the terminal. The surge transferred to the cable rises to crest in a much longer time than for the overhead line because of the greater time constant L_S/Z, attaining 2.1 per cent crest as against 2.9 per cent for the line.

In service transformer terminals may connect to a section of cable which, under certain conditions, may remain open in the manner of test *F*. In this case, as recorded in Figure 6, the cable voltage oscillates, reaching 5.2 per cent, which is nearly twice the voltage e_H divided by the turn ratio. The oscillations are largely between the short-circuit inductance (L_S) and the cable capacitance (C_C), though in part other winding effects enter into play. A chopped wave e_H results in a transferred surge of the character shown.

Under other service conditions, the section of cable may connect directly to an overhead line or continue with another cable for a great extension. The voltages developed under these conditions (test *G*) are shown in Figure 7. For either the long line or extensive cables the section of cable is not a major influencing factor. The oscillograms show that the voltages at the two ends of the cable section are much the same.

In test *H*, capacitances were connected to the open end of the cable. The capacitances applied in effect are equivalent to extending the 100-foot cable respectively to 240, 360, 580, and 1,120 feet. The results are recorded in Figure 8. The period of the transferred surge naturally increases with the capacitance, but the amplitude remains practically unchanged at 5.1 per cent.

Another practical case occurs where the transformer supplies inductive apparatus such as other transformers or rotating machines. This condition is approached in test *I*. On the basis that the short-circuit inductance (L_S) of the transformer is 100 per cent, the inductances L_L applied are respectively 26, 66, 128, and 325 per cent which values correspond to a wide range of effective loads. The oscillograms of Figure 9 show that both the amplitude and the period of the trans-

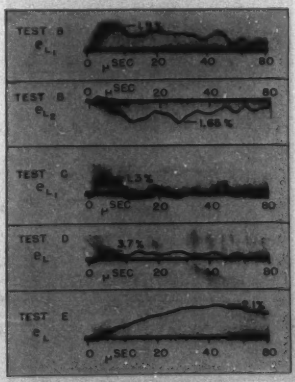


Figure 5. Oscillograms for test conditions *B*, *C*, *D*, and *E* (Figure 2)
Applied voltage e_H as in Figure 3

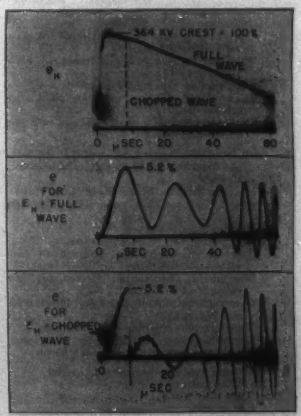


Figure 6. Oscillograms for test condition *F* (Figure 2)

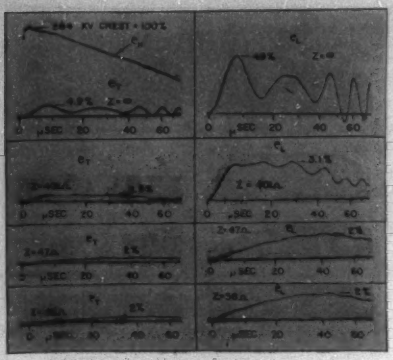


Figure 7. Oscillograms for test condition G (Figure 2)

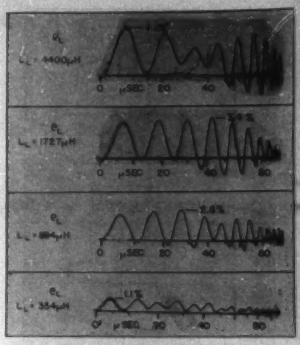


Figure 9. Oscillograms for test condition I (Figure 2)

Applied voltage e_H as in Figure 3

ferred surge decrease with decreasing inductance load.

Another set of load conditions is the combination of high surge impedances (resistances) and inductances in *J*. The corresponding transferred surges are recorded in Figure 10. These tests complete the investigation on the 1,000-kva transformer.

Other Tests and Experiences

In Figure 11 are recorded the voltages transferred through a single-phase 4,500-kva 144,000/12,000-volt, shell-form transformer. The turn ratio is 12 to 1.

Table I. Design Characteristics of Transformers Used in Tests

1. Core-form, oil-immersed, self-cooled, 1,000-kva, 76,210/2,300-volt, single-phase, 60-cycle
   - Number of turns: high-voltage, 3,576 turns; low-voltage, 108 turns
   - Turn ratio = 33.1
   - Impedance = 9.62 per cent
   - Short-circuit inductance (referred to low voltage) = 0.00135 henry
   - Short-circuit inductance (referred to high voltage) = 1.48 henrys
   - Construction, two-legged design
   - High-voltage winding, pancake coils, one column each leg
   - Low-voltage winding, two layers on each leg adjacent to core
2. Shell-form, oil-immersed, self-cooled, 4,500-kva, 144,000-120,000/12,000-volt, single-phase, 25-cycle
   - Number of turns: high-voltage, 1,582 turns; low-voltage, 132–158 turns (taps)
   - Turn ratio (in tests) = 12
   - Impedance = 4 per cent
   - Short-circuit inductance (referred to low voltage) = 0.008 henry
   - Short-circuit inductance (referred to high voltage) = 1.15 henrys
   - Construction, four high-low interleaved (see Figure 13A)
   - Two high-voltage groups each 791 turns
   - Low-voltage center group 62–88 turns (taps)
   - Two low-voltage end groups each 35 turns
3. Shell-form model, oil-immersed, special
   - No rating assigned
   - Turn ratio = 6.14
   - Construction (see Figure 12)
   - High-voltage coil group 2,180 turns
   - Low-voltage coil *A* 18 turns
   - Low-voltage coil *B* 337 turns

Other characteristics of this transformer are listed in Table I. In these tests the low-voltage winding in effect connects to a long overhead line, while the impulse voltages applied to the high-voltage winding reach practically the full test level of the insulation. The electrostatic component is clearly in evidence for the first ten microseconds; beyond this time the electromagnetic component with some superimposed oscillations of minor import is the dominating factor. In the chopped-wave test, the electromagnetic component practically disappears. The tests

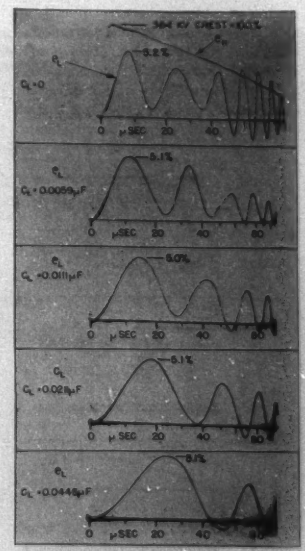


Figure 8. Oscillograms for test condition H (Figure 2)

were repeated with a 100-foot section of cable connected to the low voltage as in *B* of Figure 1. In these tests the crest voltage developed was sufficient to flash over the cable at the end.

In the course of the many commercial impulse tests applied to transformers at Sharon, the effects of surges transferred through windings have been much in evidence. Bushings of windings not under test often require protection from flashover. In this connection, it is well to point out that unusually high surge voltages can be transferred to high-voltage terminals when low-voltage windings of high insulation level are being tested. For instance, a 110-kv full-wave surge applied to the low-voltage windings of a 6,600/132,000-volt power transformer (ratio 20 to 1) is certain to flash over the high-voltage bushing.

The experience from commercial im-

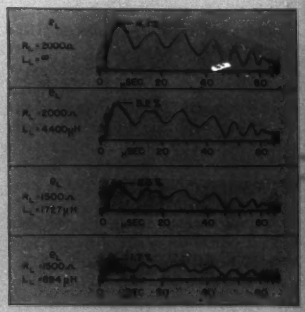


Figure 10. Oscillograms for test condition J (Figure 2)

Applied voltage e_H as in Figure 3

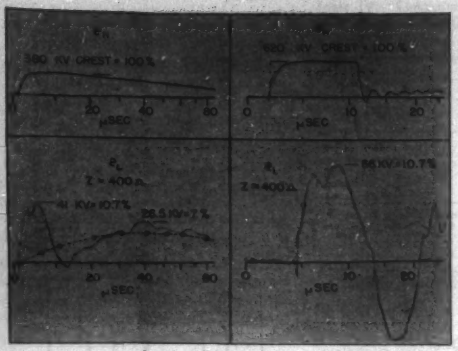


Figure 11. Oscillograms for test condition A (Figure 1) with 4,500-kva 144,000/12,000-volt single-phase shell-form transformer

Circled dots are calculated values of electromagnetic component

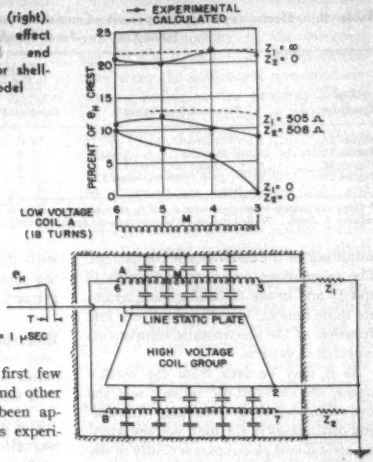


Figure 12 (right). Electrostatic effect—calculated and test data for shell-form model

pulse tests at Sharon bears out also that surges may be transferred through a number of transformers in succession. In the commercial tests, power excitation is supplied from a 5,000-kva, 2,300-volt generator of old design through a 2,000-kva 2,300/6,900-volt transformer, a 1,000-foot cable, and again through another 2,000-kva transformer which serves to adjust the 6,900-volt cable supply to the primary voltage of the transformer under impulse test. Depending on the nature of the commercial impulse test, transferred surges of various intensities would reach the rotating machine. These seriously damaged the machine windings on three occasions in the course of the first few years. Suitable capacitances and other protective devices have since been applied and no further difficulties experienced.

Electrostatic Component and Oscillations

The factors which affect the electrostatic component are several. These are discussed here in simple practical terms with reference to the typical examples in Figures 12 and 13. The electrostatic voltage induced in the low-voltage winding depends upon the capacitance relation between the high and low-voltage windings and to ground. In turn, the voltage induced in the low-voltage winding is discharged through the inductance of part of the winding into the terminal impedance. Thus from the simplified circuit in *C* of Figure 13 for the abrupt surge e_H,

$$e_L \approx \frac{C_1}{C_1+C_2} \cdot \frac{Z\epsilon^{-\frac{Z}{2L}t} \sin t\sqrt{\frac{1}{LC_2}-\frac{Z^2}{4L^2}}}{\sqrt{\frac{L}{C_2}-\frac{Z^2}{4}}}\, e_H \qquad (1)$$

The calculated values from this simplified approach are in fairly good agreement with the test results. A more rigorous analysis requires that account be taken of the additional circuit elements shown in Figures 12 and 13 but in so doing the solution becomes quite complex.

Simply stated, the electrostatic component depends on the ratio, Z divided by $\sqrt{L/C_2}$, and on the length of the front of surge e_H with respect to the natural period $2\pi\sqrt{LC_1}$. In the case of a long cable where Z is small or for a segment of cable of large capacitance, the electrostatic component disappears. The electrostatic component needs be considered only where the low-voltage winding connects to aerial lines, to highly inductive apparatus or machinery, to loads of effectively high impedance, and where the capacitance to ground is small. The physical characteristics of the transformer windings are a factor, but these do not bear any simple relation in terms of the usual design constants. The ratio of the insulation test levels of the windings is a measure of the factor $C_1/(C_1+C_2)$ and, other things being equal, of the relative

Figure 13. Electrostatic effect—calculated and test data for 4,500-kva shell-form transformer

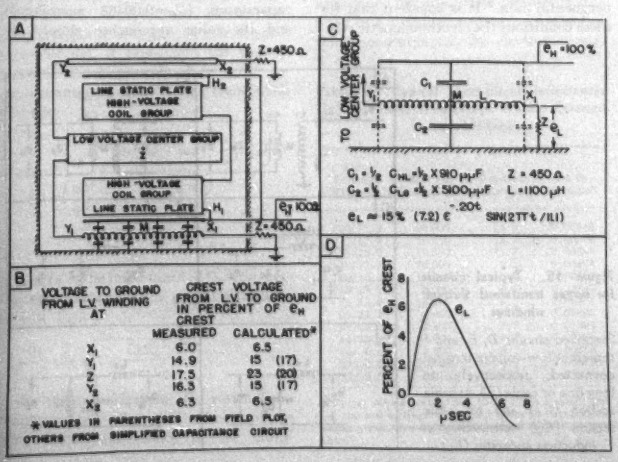

A
Z = 450 Ω
LINE STATIC PLATE
HIGH-VOLTAGE COIL GROUP
LOW VOLTAGE CENTER GROUP
HIGH VOLTAGE COIL GROUP
LINE STATIC PLATE
e_T 100 Ω
Z = 450 Ω
B
VOLTAGE TO GROUND FROM LV WINDING AT
CREST VOLTAGE FROM LV TO GROUND IN PERCENT OF e_H CREST
MEASURED
CALCULATED*
X_1 6.0 6.5
Y_1 14.9 15 (17)
Z 17.5 23 (20)
Y_2 16.3 15 (17)
X_2 6.3 6.5
*VALUES IN PARENTHESES FROM FIELD PLOT, OTHERS FROM SIMPLIFIED CAPACITANCE CIRCUIT
C
TO LOW VOLTAGE CENTER GROUP
e_H = 100 %
$C_1 = \frac{1}{2}\ C_{HL} = \frac{1}{2} \times 3100\ \mu\mu F$
$Z = 450\ \Omega$
$C_2 = \frac{1}{2}\ C_{LG} = \frac{1}{2} \times 5100\ \mu\mu F$
$L = 1100\ \mu H$
$e_L \approx 15\%\ (7.2)\ \epsilon^{-.20t} \sin(2\pi t/11)$
D
PERCENT OF e_H CREST
e_L
μSEC

Table II. Electromagnetic Component—Comparison of Calculated Data With Tests for 1000-Kva Core-Form Transformer

Test Condition	Terminal Impedance	Crest Voltage e_L in Per Cent e_H Crest: Calculated*	Crest Voltage e_L in Per Cent e_H Crest: Experimental	Wave Form
Figure 2A	Z_L=379 ohms	2.6	2.9	See Figure 14 for comparison of calculated* and recorded wave form
Figure 2E	Z_L= 46 ohms	1.6	2.1	
Figure 2F	C_C=0.00468 microfarad	5.8	5.2	
Figure 2H	C_C+C_L=0.0493 microfarad	5.2	5.1	

* Data calculated from equations 2 and 3, transformer constants in Table I, and terminal impedances in column 2 above. Wave form of e_H in calculations approximately as in tests.

amplitude of the electrostatic component. The calculations and tests in Figures 12 and 13 and in the preceding oscillograms are quite indicative of the amplitude and duration of the electrostatic components expected in general.

As it may be seen from the oscillograms, the electrostatic impact sets the low-voltage winding oscillating. In addition oscillations in the high-voltage winding are induced electromagnetically in the low-voltage winding, and these in turn appear in the transferred surge. Simplified calculations of these effects are beset with difficulties. In general, however, the superimposed oscillations are not of primary importance.

Table III. Comparison of Period of Oscillation for Various Cable Capacitances

Short-Circuit Inductance (L_S in Microhenrys)	Cable Capacitance (C_C in Microfarads)	Period of Oscillation: Calculated ($T=2\pi\sqrt{L_S C_C}$) (Microseconds)	Period of Oscillation: Experimental (Figure 8) (Microseconds)
1,350	0.00468	15.8	16
1,350	0.0106	24.8	23
1,350	0.0158	29.0	28
1,350	0.0258	37.0	38
1,350	0.0493	51.3	52

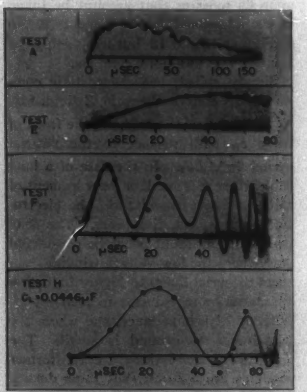


Figure 14. Electromagnetic effect—calculated (circled dots) and test waves of e_L for 1,000-kva core-form transformer

Test conditions *A*, *E*, *F*, and *H* (Figure 2)

Electromagnetic Effect

Surge Transferred to a Long Line or Cable

The general solution for the electromagnetic component is treated in the appendix. From a practical standpoint, refer to the equivalent simplified circuit of Figure 15D and let

$e_H=Ee^{-at}$=impulse voltage applied to high-voltage winding
L_S=short-circuit inductance of transformer (referred to low-voltage side)
N=turn ratio
Z=surge impedance of line or cable

Then the electromagnetic component transferred to the line or cable is

$$e_L=\frac{Z}{Z-aL_S}\left[\epsilon^{-at}-\epsilon^{-\frac{z}{L_S}t}\right]\frac{E}{N} \qquad (2)$$

In Figures 11 and 14 and in Table II are compared the calculations for three typical cases with the corresponding experimental data. It is apparent that for these conditions the electromagnetic component is conducive to fairly good predetermination. The preceding equation can be adapted readily to similar conditions such as those shown in tests *B*, *C*, and *D* of Figure 2. The behavior for shorter lengths of cable and line is considered in the following section.

Surge Transferred to Section of Cable (or Line)

For this condition the simplified circuit of Figure 15E applies. Let the applied voltage $e_H=Ee^{-at}$, then

$$e_L=\left[\frac{\epsilon^{-at}}{1+\left(\frac{a}{\omega}\right)^2}+\frac{\sin\left(\omega t-\tan^{-1}\frac{\omega}{a}\right)}{\sqrt{1+\left(\frac{a}{\omega}\right)^2}}\right]\frac{E}{N} \qquad (3)$$

where $\omega=1/\sqrt{L_S C_C}$ and C_C=capacitance of cable section.

On the whole, the comparison between the calculated and experimental data in Figure 14 and in Table II for the 106-foot section of cable is good. Equation 3, however, does not take into account the attenuation due to losses, nor does it consider the capacitance of the windings and other effects which apparently are responsible for the "beat-note" phenomena present in the oscillations.

As shown in the oscillograms of Figure 7, the cable section terminating in a lumped impedance equal to the surge impedance of the cable behaves essentially as a continuous long cable. In the case where the cable section connects to a long overhead line, the cable voltage no longer is oscillatory. The reason for this lies in the fact that the line surge impedance (Z=401 ohms) appears in Figure 15E as a circuit element shunting the cable capacitance (C_C=0.00468 microfarad), and its value approaches closely the

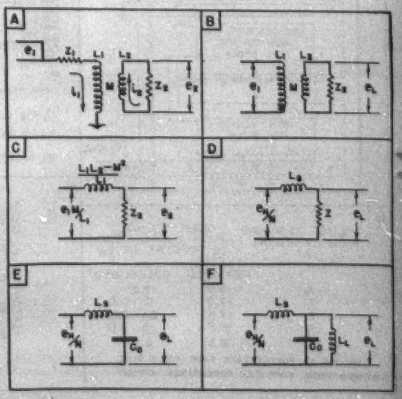


Figure 15. Typical circuits for surges transferred through windings

Simplified circuits *D*, *E*, and *F* represent low-voltage terminal connected, respectively, to long line or cable (Z), to cable section (C_C) and to cable section (C_C) terminating at induction apparatus (L_L)

critical damping impedance $\frac{1}{2}\sqrt{L_S/C_C}$ = 270 ohms.

In test H of Figure 2, the load capacitances amount in effect to extending the cable section. The surge transferred to these sections is given by equation 3 where the cable capacitance in the equation now becomes $C_O = C_C + C_L$. In Table III are compared the calculated and experimental periods of oscillation for the various cable capacitances.

In Figure 14 and Table II are compared the calculated and experimental data of the transferred voltage for $C_L = 0.0446$ microfarad. This load capacitance is equivalent to extending the cable to 1,120 feet. In an actual section of this length, the cable would have an inductance less than ten per cent of L_S. For a much longer section, it is apparent that, besides the capacitance, the inductance of the cable need be considered. That is, in Figure 15E for segments of cable where the total inductance $L_C = Z^2 C_C$ (constants of cable) is small relative to the transformer short-circuit inductance L_S, the cable may be treated as a lumped capacitance. For longer sections where the cable inductance becomes appreciable but is not excessively large compared to L_S, the cable may be replaced with good approximation by its equivalent π circuit. For still longer sections of cable (or line), transferred surges should be dealt with in terms of traveling-wave phenomena.

Surge Transferred to Section of Cable and Terminating Inductive Apparatus

For this condition the simplified circuit is given in Figure 15F. The capacitance C_C includes the capacitance of the connecting apparatus, or, in the absence of a cable section, it represents the capacitance of the apparatus alone. For an applied surge $e_H = Ee^{-\alpha t}$, the transferred surge is

$$e_L = \left[\frac{\epsilon^{-\alpha t}}{1+\left(\frac{\alpha}{\omega}\right)^2} + \frac{\sin\left(\omega t - \tan^{-1}\frac{\omega}{\alpha}\right)}{\sqrt{1+\left(\frac{\alpha}{\omega}\right)^2}} \right] \times \frac{L_L}{L_S+L_L} \cdot \frac{E}{N} \quad (4)$$

where L_L is the inductance of the connecting apparatus, and the period of oscillation is

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{C_C \frac{L_S L_L}{L_S+L_L}}$$

In the investigation, L_L varies from approximately 25 to 325 per cent of the short-circuit inductance of the transformer (L_S), and therefore these values comprehend a wide range of inductances of the connecting apparatus (transformers, rotating machines, and so forth). In Table IV are compared the calculated and experimental data of the transferred surges appearing at the connecting apparatus. The good agreement again confirms the applicability of the simplified methods for practical calculations.

Table IV. Comparison of Calculated Data With Tests—Cable Section and Inductive Apparatus Connected to Secondary of 1,000-Kva Core-Form Transformer

Test Condition	Terminal Inductance (Henry)	Period of Oscillation (Microseconds)		Crest Voltage e_L in Per Cent e_H Crest	
		Calculated*	Experimental	Calculated*	Experimental
Figure 21	$L_L = 0.000354$	7.2	8.	1.2	1.1
Figure 21	$L_L = 0.000894$	10.	11.	2.4	2.6
Figure 21	$L_L = 0.001727$	12.	12.5	3.4	3.4
Figure 21	$L_L = 0.004400$	14.	14.	4.6	4.1

* Calculated data based on equation 4, and circuit constants in Table I, Figure 21, and column 2 above. Crest voltage was determined from equation 4 simplified to $(2E/N)\cdot(L_L/L + L_L)$.

Application Problems

The problems encountered in practice are of a varied character, but in general they can be reduced to one of the several conditions in Figure 2 or to modifications and combinations of these. The electrostatic component need be considered only when terminals are left open or connected to an overhead line or other high-impedance circuits. The method is outlined in a previous section. In many of the cases examined, the electromagnetic component alone required attention. The transferred surge then is conducive to calculation according to the foregoing equations 2, 3, and 4, or similar derivations from the equivalent simplified circuit applicable to the problem (Figure 15). The crest voltage of the transferred surge is related to the turn-ratio relation, e_H/N, by a factor A which depends largely on the terminal conditions, the short-circuit inductance (L_S), and the wave of the surge applied (e_H). Typical values of the short-circuit inductance for power transformers are given in Table V.

Table V. Typical Short-Circuit Inductances (L_S) for Power Transformers Values Referred to Low Voltage

Line Voltages (Kilovolts)	Kva Per Transformer	Per Cent Impedance	L_S in Henrys*
220/13.2	20,000	14.8	0.00342
220/13.2	10,000	12.5	0.00578
154/13.2	10,000	11.7	0.00540
132/13.2	10,000	9.2	0.00425
110/13.2	10,000	8.7	0.00402
110/13.2	5,000	8.1	0.00748
66/13.2	10,000	8.1	0.00374
66/13.2	5,000	7.5	0.00692
66/13.2	2,500	7.0	0.01292
44/13.2	10,000	6.2	0.00286
44/ 6.6	2,500	6.2	0.00286
22/ 6.6	10,000	6.2	0.00072
22/ 6.6	2,500	6.2	0.00286

* These values correspond to 60-cycle ratings and for the low-voltage connected delta in three-phase bank. For wye connection reduce values to one third.

In practice, transformers usually are installed in three-phase banks, a condition which results in a transferred surge of equal or lower amplitude than for the single-phase connection previously discussed. For a surge e_H on one phase or simultaneous surges on two phases, the transferred voltage to ground is related to the single-phase transformer connection by the conversion factor K_A in Table VI for the various three-phase bank connections. Correspondingly, the duration of the front of the transferred surge is affected by the factor K_F indicated in the table. For simultaneous surges on all three phases, the electromagnetic component disappears (except for the wye-wye bank connection with both neutrals grounded). Thus the crest voltage of the transferred surge is given by the expression

$$e_L\,(\text{electromagnetic}) = \frac{e_H}{N} \cdot A \cdot K_A \quad (5)$$

A typical example will serve to illustrate the application of equation 5. A wood-pole line connects to a 115,000/13,200-volt, grounded-neutral wye–delta transformer bank. The secondary supplies, through a 125-foot cable, an industrial network which consists of a number of transformer units each feeding individual loads. On a single-phase basis, the circuit corresponds in effect to Figure 15F. In this case, the effective load inductance L_L and the short-circuit inductance L_S are of the same order so that the amplitude factor A in equation 4 is close to unity. The conversion factor for the three-phase bank is $K_A = 0.33$. The advantage of arrester protection on the high side in limiting the transferred voltage is apparent. In the event of a severe lightning surge on the wood-pole line, a full-rated high-voltage arrester limits e_H to 450 kv or to a proportionally lower value, provided an 80 per cent arrester is permissible. Then from equation 5 the transferred voltage is $(450/5)1\times0.33 = 30$ kv. In the absence of arrester protection on

the high side, and should the industrial load become disconnected, the transferred surge across the secondary terminals and the cable may well reach 100 kv.

Similar problems arise in connection with rotating machines. These often supply transformer banks which connect on the high side to overhead lines exposed to lightning. The protection of rotating machines against surges requires that the voltage to ground at the machine should be limited to approximately the low-frequency test voltage of the machine, and, in order to limit the voltage between turns, the front of the surge appearing at the machine should as a rule exceed ten microseconds. The protection of machines is discussed in detail elsewhere.[8,9] The methods presented here are helpful in determining the transferred surge that may appear at the machine. In general, the transformer bank in conjunction with lightning arresters on the high side, as well as cable sections in the low-voltage circuit, usually provides substantial protection to machines. However, each case must be examined individually and on its merits. In important installations or for machines of older design located in vital zones, the addition of special protection at the machines may be justified.

In the problems on transferred surges that have been examined: in some, no protection was found necessary on the nonexposed circuit; in others, adequate protection on the exposed circuit also would provide protection to the nonexposed circuit; in some instances, the addition of protection on the nonexposed circuit appeared desirable. An analysis of the problem in each case provided the basis for sound engineering recommendations.

Appendix

Referring to Figure 15A where rectangular surge e_1 is applied to the primary winding over a transmission line and the secondary connects to a line, the transferred surge e_2 is derived from the circuit equations (expressed operationally)

$$e_1 = L_1 p i_1 + Z_1 i_1 - M p i_2$$
$$0 = L_2 p i_2 + Z_2 i_2 - M p i_1$$

The solution is

$$e_2 = \frac{2MZ_2}{\sqrt{(L_1Z_2 - L_2Z_1)^2 + 4Z_1Z_2M^2}} \times \epsilon^{-\frac{L_1Z_2 + L_2Z_1}{2(L_1L_2 - M^2)}t} \times \sinh \frac{\sqrt{(L_1Z_2 - L_2Z_1)^2 + 4Z_1Z_2M^2}}{2(L_1L_2 - M^2)} t \cdot e_1 \quad (6)$$

In the usual case $L_1 \gg M \gg L_2$, so that, in effect, equation 6 reduces to

$$e_2 = \frac{M}{L_1}\left[1 - \epsilon^{-\frac{L_2Z_1}{L_1L_2 - M^2}t}\right] e_1 \quad (7)$$

Table VI. Factors Applied to e_L for Conversion From Single-Phase to Three-Phase Connections*

Bank connections high-voltage to low-voltage winding			
Grounded wye to grounded wye	Grounded wye to wye	Wye to delta	
Delta to grounded wye	Wye to grounded wye	Delta to delta	Grounded wye to delta
Delta to wye	Wye to wye		
K_A (amplitude)	1.00	0.67	0.33
K_F (front length)	1.00	0.33	0.33

* For derivation, see paper by Palueff and Hagenguth, reference 1; also see appendix of this paper. The conversion factors correspond here to turn ratio. Application is discussed in equation 5.

That is, in the usual practical problem Z_1 is of secondary or no importance because of the relatively high value of L_1. Circuit A simplifies to B or its equivalent C which, in terms of the turn ratio (N) and short-circuit inductance of the transformer (L_S), becomes circuit D. For a steep-front, exponential-tail surge e_H, the solution of e_L is equation 2.

Should the secondary in Figure 15A connect to a cable section of capacitance C_2, from the circuit

$$e_2 = \frac{M}{(L_1L_2 - M^2)C_2} \times \frac{p}{p^3 + \frac{L_2Z_1}{L_1L_2 - M^2}p^2 + \frac{L_1}{(L_1L_2 - M^2)C_2}p + \frac{Z_1}{(L_1L_2 - M^2)C_2}} \cdot e_1$$

$$e_2 = \frac{M}{(L_1L_2 - M^2)C_2} \cdot \frac{p}{(p+\lambda)[(p+\beta)^2 + \omega^2]} \cdot e_1$$

and the solution is

$$e_2 = \frac{M}{(L_1L_2 - M^2)C_2} \times \frac{1}{(\lambda - \beta)^2 + \omega^2} \left[\epsilon^{-\lambda t} + (\lambda - \beta)\epsilon^{-\beta t} \sin \omega t - \epsilon^{-\beta t} \cos \omega t\right] e_1 \quad (8)$$

For the common case $L_1 \gg M \gg L_2$, the circuit simplifies to Figure 15E. For a steep-front exponential-tail surge e_H, e_L is given by equation 3. Similarly, for a cable section and inductive apparatus, we have Figure 15F and equation 4. The transferred surge e_L for other terminal conditions can be derived in like manner.

For three-phase bank connections the solution of the transferred surge is the same form as for the single-phase, except that the conversion factors K_A and K_F appear, respectively, in the amplitude and time constant of the equations. Consider for instance the wye-wye connection (see Table VI), a rectangular surge e_1 applied to one terminal, and for the practical case considered here neglect Z_1. Current i_1 flows in the phase to which e_1 is applied and $i_1/2$ in the other two phases, all in the same direction. In the corresponding secondary windings the currents are i_2, $i_2/2$ and $i_2/2$. We then have the circuit equations

$$e_1 = \frac{3}{2}L_1 p i_1 - \frac{3}{2}M p i_2$$
$$0 = \frac{3}{2}L_2 p i_2 - \frac{3}{2}M p i_1 + \frac{3}{2}Z_2 i_2$$

The maximum voltage to ground is

$$e_2 = i_2 Z_2 = \frac{2}{3} \cdot \frac{M}{L_1}\left[1 - \epsilon^{-\frac{L_2Z_1}{L_1L_2 - M^2}t}\right] e_1 \quad (9)$$

Thus for this connection $K_A = 2/3$ and $K_F = 1$.

For the wye-delta connection the circuit equations are

$$e_1 = 3/2 L_1 p i_1 - 3/2 M p i_2$$
$$0 = L_2 p i_2 - M p i_1 + 3 Z_2 i_2$$

and

$$e_2 = \frac{1}{3} \cdot \frac{M}{L_1}\left[1 - \epsilon^{-\frac{2L_2Z_1}{L_1L_2 - M^2}t}\right] e_1 \quad (10)$$

so that, $K_A = 1/3$ and $K_F = 1/3$.

The conversion factors for other three-phase bank connections can be derived in a similar manner or by methods described elsewhere.[1] Their values for the various connections are given in Table VI.

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Effect of Wave Form on Let-Go Currents

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MEMBER AIEE

Synopsis: This paper is a continuation of "Effect of Frequency on Let-Go Currents"[2] and concludes studies made to determine let-go currents. This paper extends the analysis to cover various wave shapes and includes a method of determining reasonably safe currents for men, women, and children, for sine waves, direct current, and complex wave forms containing both a-c and d-c components. As in previous papers, conclusions regarding reasonably safe electric currents are based on the criterion that a safe current is the let-go current for 99½ per cent of a large group of healthy subjects.

ALTHOUGH it has been demonstrated that let-go currents, and hence the electric-shock hazard due to relatively small electric currents, are controlled by the crest value of an a-c wave and not by its root-mean-square value, the significance of this fact has received little attention. Previous papers on the general subject[1,2] have been concerned chiefly with developing a method of analysis and establishing concepts of reasonably safe sine-wave electric currents for various frequencies and for direct current. The procedure disclosed in this paper extends the analysis to permit estimating reasonably safe let-go currents for practically any commercial wave form, from sine-wave alternating current on one hand to pure direct current as the other extreme. The results of the analysis are believed to be important in increasing the safety of certain electronic devices, filters, and communication circuits, to the end that the sustained shock current obtained from parts of the circuit readily accessible to an operator may be held within reasonably safe or known limits. Also, the results may have value in specifying allowable leakage current to the chassis of radiobroadcast receivers; for improved design of high-voltage television power supplies; for defining the permissible magnitude of the components in the sustained output current from capacitor-discharge electric-fence controllers, and other similar apparatus. Although the conclusions have been based largely on experiments made with 60-cycle alternating current and direct current, the results may also be used for cases involving higher frequencies, but with increased factor of safety.

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Data presented in this paper were obtained under the supervision of Major John B. Lagen, Medical Corps, United States Army; and Eric Ogden, professor of physiology, University of Texas Medical Branch, and consulting physiologist, John Sealy Hospital, Galveston, Tex. At the time this study was made Major Lagen was assistant professor of medicine and pharmacology, University of California Hospital, San Francisco, Calif., and Professor Ogden was associate professor of physiology, University of California Medical School, Berkeley, Calif. Acknowledgments are also given the men and women who volunteered for these experiments without whose interest and co-operation this work would have been impossible.

Results

Mean let-go current values obtained from tests made with various wave shapes follow the same curve if the crest value of the a-c component is plotted on one axis versus the d-c component on the other. Two conditions must be met in order to have the experimental data fall on the same curve. These conditions are:

1. The reference axis for measurement of the alternating component must be the average value or the direct component.

2. The peak or crest value of the alternating component must be measured in the direction of the maximum total current.

These requirements are illustrated in Figure 1, which gives sketches of the wave forms used in these experiments.

When measurements were made according to these two conditions, points representing the mean let-go current obtained from groups of subjects tested on sine-wave alternating current, direct current, and the four complex wave forms of Figure 1 fell closely on the top curve of Figure 2. The fact that the points fell on the same curve is important, because it permits estimating let-go currents for other wave forms as well as those used to locate the curve. Thus, from two simple measurements one may determine the probable shock hazard for electric currents of any assumed wave form. The 99.5 percentile curves for men and women were computed from equations 3 and 4, reference 2. In the absence of experimental data, the reasonably safe current for children was taken as 50 per cent of the safe values for men. Percentile curves for either more conservative or more liberal probabilities may be computed readily by using a similar procedure.

In these experiments sine waves were superimposed on pure direct current to give the wave forms illustrated in Figures 1B and 1C. In these tests crest A was equal to crest B, and the requirement that the peak of the alternating component be measured in the forward direction, or in the direction of the maximum total current, was unnecessary. The current wave of Figure 1B was similar but not identical to that obtained from the filtered output of an ordinary rectifier. Measurements were made to determine the alternating component of two rectifiers using a shunt and a crest vacuum-tube voltmeter calibrated to read milliamperes. Considerable difference in the magnitude of the opposite crests was obtained, which emphasized the importance of selecting the proper crest of the a-c ripple when using the method for practical problems.

The importance of determining the crest of the alternating component in the direction of the maximum total current is further illustrated from consideration of the wave forms of Figures 1D and 1E. These current waves represent the output from a half-wave and a full-wave rectifier, respectively. Consider crest B for either case. The vacuum-tube crest milliammeter indicated a definite reading when connected to measure crest B, even though the total current was zero. This

Table I. Effect of Wave Form on 180-Cycle Let-Go Current

Subject No.	Triangular Wave		Sine Wave	
	Crest Milliamperes	Rms Milliamperes	Crest Milliamperes	Rms Milliamperes
2	22.1	12.8	21.4	15.1
12	22.6	13.0	21.9	15.5
21	30.0	17.3	42.4	30.0
22	38.7	22.3	36.3	25.7
23	25.2	14.5	23.2	16.4
27	21.2	12.2	20.1	14.2
30	37.1	21.4	31.7	22.4
31	25.5	14.7	25.2	17.8
32	26.0	15.0	23.3	16.5
36	26.0	15.0	25.7	18.2
37	34.4	19.8	32.5	23.0
40	27.2	15.7	25.5	18.0
45	26.8	15.5	23.5	16.6
54	27.7	16.0	32.8	23.2
55	30.3	17.5	26.0	18.4
61	27.4	15.8	29.4	20.8
64	30.0	17.3	30.0	21.2
67	24.0	13.8	23.9	16.2
74	24.1	13.8	23.8	16.8
Mean	27.7	16.0	27.2	19.3

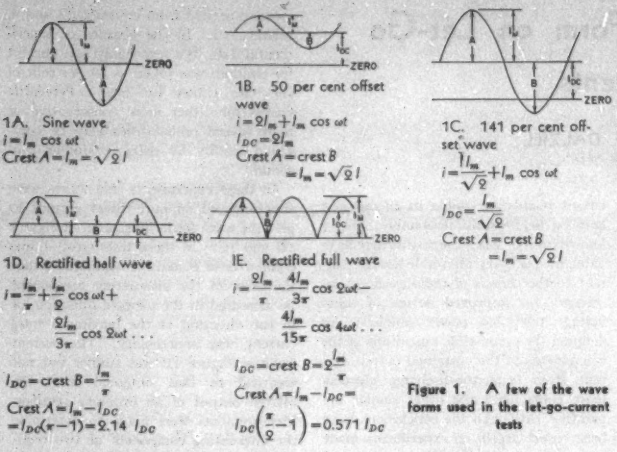

ZERO
1A. Sine wave
$i = I_m \cos \omega t$
Crest $A = I_m = \sqrt{2}\, I$
1B. 50 per cent offset wave
$i = \sqrt{2} I_m + I_m \cos \omega t$
$I_{DC} = \sqrt{2} I_m$
Crest A = crest B
$= I_m = \sqrt{2}\, I$
1C. 141 per cent offset wave
$i = \frac{I_m}{\sqrt{2}} + I_m \cos \omega t$
$I_{DC} = \frac{I_m}{\sqrt{2}}$
Crest A = crest B
$= I_m = \sqrt{2}\, I$
1D. Rectified half wave
$i = \frac{I_m}{\pi} + \frac{I_m}{2} \cos \omega t + \frac{2 I_m}{3\pi} \cos 2\omega t \ldots$
$I_{DC} = \text{crest } B = \frac{I_m}{\pi}$
Crest $A = I_m - I_{DC}$
$= I_{DC}(\pi - 1) = 2.14\ I_{DC}$
1E. Rectified full wave
$i = \frac{2 I_m}{\pi} - \frac{4 I_m}{3\pi} \cos 2\omega t - \frac{4 I_m}{15\pi} \cos 4\omega t \ldots$
$I_{DC} = \text{crest } B = \frac{2 I_m}{\pi}$
Crest $A = I_m - I_{DC} =$
$I_{DC}\left(\frac{\pi}{2} - 1\right) = 0.571\ I_{DC}$

Figure 1. A few of the wave forms used in the let-go-current tests

was due to the fact that the alternating component and the direct component were equal and opposite for the instant considered. It would be surprising indeed if let-go currents were controlled by crest B. As far as determined, there are only two important factors which control let-go currents. These are crest A of the alternating component and I_{DC}, the average value, or the direct component of the wave. The required measurements may be made easily with direct reading instruments. The direct component may be measured with an ordinary d-c milliammeter, and the alternating component may be measured with a half-wave crest vacuum-tube instrument in conjunction with a cathode-ray oscilloscope. The latter is used to permit selecting crest A instead of crest B. Of course, the values may be obtained from a calibrated oscillogram, but this procedure is cumbersome and requires photographic processes.

Although the curves of Figure 2 were determined from six series of tests using 60 cycles and direct current, it is believed that conclusions based thereon will be conservative for wave forms containing higher harmonics or other wave forms likely to be met in practice. Let-go currents for sine waves have a broad minimum from about 15 cycles to 100 cycles. The reasonably safe current curves of Figure 3 indicate that human tolerance increases slowly at first and then quite rapidly for frequencies below or above this range. Predictions made from the curves of Figure 2 for alternating components having frequencies outside the middle band in reality assume that the let-go-current curves are straight lines tangent to the curves of Figure 3 at their lowest points. The predictions may therefore be conservative and well on the side of safety.

The relative-discomfort curve of Figure 3 was obtained by plotting the reciprocals of the average let-go current values for each frequency, that is, the reciprocal of the corrected mean currents, Table I, reference 2. The vertical scale was arranged so that the discomfort would be 100 per cent for 60 cycles. The curve indicates the relative discomfort caused by a given current for the frequency range included in the graph. Although a subject's let-go current increases considerably at the very low frequencies, his muscles follow the current variations, and the sensations, presumably caused by the peaks of the current wave, are more painful than those experienced on the 60-cycle tests. At very high frequencies, sensations of heat rather than pain predominate. The term "relative discomfort" must therefore be given a broad interpretation, and, in the absence of a means of specifying varying degrees of pain, the curve may be taken to show in a general way the discomfort or the relative danger of a given current as a function of frequency.

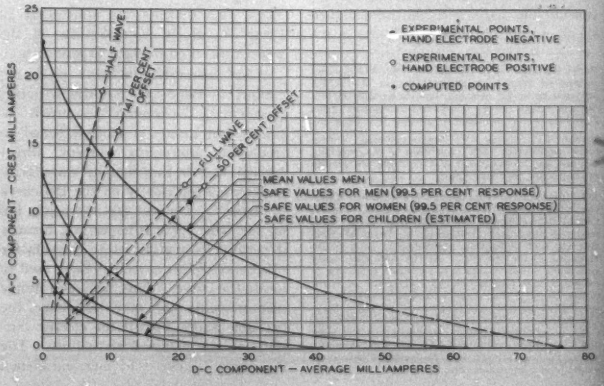
Experimental Data and Analysis

Effects of A-C Wave Form on Let-Go Currents

Before investigating the reactions produced by composite currents, it was considered desirable to make an additional investigation of the effect of wave form on let-go currents for complex alternating currents, that is, for wave forms containing no direct component. As previously reported, let-go currents appeared to be controlled by the crest and not by the root-mean-square (rms) value of the current. In these tests, comparisons were made for 60-cycle sine-wave current alone and in combination with a third harmonic equal to approximately 37½ per cent of the fundamental. In one case, the third harmonic was phased so that the resultant wave was sharply peaked. For the other case, the third harmonic was shifted 180 degrees to produce a relatively flat-topped wave. Inspection of the data obtained from 26 subjects indicated that let-go currents were controlled by the peak of the current wave and not the root-mean-square value.[1]

A second series of tests was conducted subsequently in which let-go currents

Figure 2. Let-go-current curves plotted as a function of a-c and d-c components



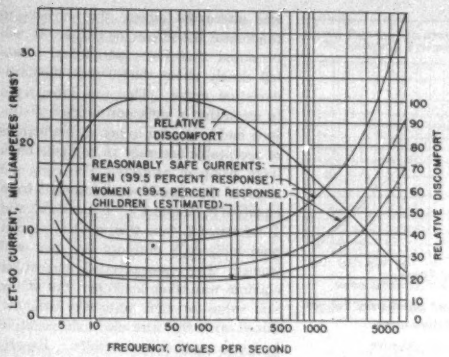


Figure 3. Sine-wave let-go currents and relative discomfort curves versus frequency

for 19 subjects were measured using sine and triangular waves of 180 cycles frequency. An oscillogram of the triangular current wave is shown in Figure 4. The triangular wave was obtained from a rheostat connected across the terminals of the interphase transformer of a small six-phase hot-cathode thyratron rectifier supplying a resistance load. Sine-wave 180-cycle currents were obtained from a beat-frequency oscillator and power amplifier. Experimental data for this test are given in Table I. The number 6 copper-wire electrode wet with salt solution was used for this test and for all other tests discussed in this paper. Although the let-go values were slightly more erratic than those observed for the 60-cycle wave-form tests, comparison of most individuals' values and the mean values for the group corroborate the conclusion that the crest of the a-c wave is the major factor which controls the let-go current.

Reasonably Safe 60-Cycle Sine-Wave Currents for Adults

The following data and analyses were taken from reference 2. The mean sine-wave 60-cycle let-go current for men was 15.87 rms milliamperes = 22.4 crest milliamperes. The 99.5 percentile = 15.87 (1 − 0.432) = 9 rms milliamperes = 12.7 crest milliamperes (from equation 1). The mean sine-wave 60-cycle let-go current for women was 10.5 rms milliamperes = 14.8 crest milliamperes. The 99.5 percentile = 10.5 (1 − 0.432) = 5.95 rms milliamperes = 8.4 crest milliamperes. These values were plotted on the vertical axis of Figure 2 to anchor the curves at this end of the graph.

Reasonably Safe 60-Cycle Sine-Wave Currents for Children

Obtaining let-go currents for young children appears difficult if not impossible of accurate determination. In addition to the reluctance of parents to permit experimentation on their children, limited experience indicates that children are likely to refuse to volunteer for a sufficient number of trials to permit determination of their let-go current with any degree of accuracy. As previously mentioned[1] let-go currents appear related to the muscular development of the wrist and forearm. However, all attempts to find a correlation, other than general appearance, with age, weight, strength of grip, or arm measurements were without conclusive results. In view of the early development of the grip of children it might be expected that their let-go currents would be relatively large; moreover it is a common observation that children appear to be very hardy in their ability to withstand a variety of conditions which would be disastrous to adults. In the interest of establishing a reasonably safe current for normal healthy children, and in the absence of experimental data, it seemed reasonable to estimate the probable safe current for children as 50 per cent of the safe value for normal adult males. Reactions caused by currents of this magnitude were unobjectionable to the men, and they were found to be amply safe for three small boys tested. The following are the 60-cycle sine-wave let-go currents obtained on the boys:

Age 5 years . . . . . Let-go current 7 rms milliamperes*
Age 9 years 3 months . . Let-go current 7.6 rms milliamperes
Age 10 years 11 months . . Let-go current 9 rms milliamperes

Accordingly, the reasonably safe sine-wave value for normal children was com-

Table II. Let-Go Currents—Sine-Wave and 141 Per Cent Offset-Wave Tests

Hand Electrode Positive			Hand Electrode Negative		
Subject No.	Sine-Wave Control 60-Cycle (Rms Milliamperes)	Offset-Wave A-C Component (Rms Milliamperes)	Subject No.	Sine-Wave Control 60-Cycle (Rms Milliamperes)	Offset-Wave A-C Component (Rms Milliamperes)
73	9.2	7.7	73	9.2	7.5
104	12.6	10.0	104	12.6	8.0
128	13.2	10.0	123	17.8	8.8
93	15.9	11.2	93	15.9	9.3
99	15.8	11.6	99	15.8	9.4
130	16.9	12.2	130	16.9	10.4
124	16.5	12.7	124	21.5	10.5
134	18.1	13.0	132	19.4	11.5
132	19.4	13.0	128	13.2	11.6
			129	16.5	12.0
			134	15.1	12.3
Mean	14.96	11.27		15.81	10.12
Corrected mean:					
D-c average and a-c rms	11.27 × 15.87/14.96 = 11.96 milliamperes		10.12 × 15.87/15.81 = 10.16 milliamperes (equation 2, reference 2)		
A-c crest	√2 × 11.96 = 16.91 milliamperes		√2 × 10.16 = 14.37 milliamperes (see Figure 1C)		
99½ percentile:					
A-c crest men	16.91(1.0 − 0.432) = 9.60 milliamperes		14.37(1.0 − 0.432) = 8.16 milliamperes		
D-c average men	11.96(1.0 − 0.432) = 6.79 milliamperes		10.16(1.0 − 0.432) = 5.77 milliamperes (equation 3, reference 2)		
A-c crest children	0.5 × 9.60 = 4.8 milliamperes		0.5 × 8.16 = 4.1 milliamperes		
D-c average children	0.5 × 6.79 = 3.4 milliamperes		0.5 × 5.77 = 2.9 milliamperes		
A-c crest women	9.60 × 10.5/15.79 = 6.4 milliamperes		8.16 × 10.5/15.87 = 5.4 milliamperes		
D-c average women	6.79 × 10.5/15.87 = 4.5 milliamperes		5.77 × 10.5/15.87 = 3.8 milliamperes (equation 4, reference 2)		
Polarity effect	10.16/11.96 = 0.85				

* Determined by Royce E. Johnson, director, electrical standards laboratory, University of Wisconsin, Madison, Wis.

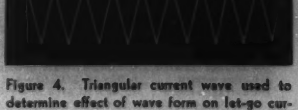


Figure 4. Triangular current wave used to determine effect of wave form on let-go currents for complex a-c wave forms

puted as $0.50 \times 9 = 4.5$ rms milliamperes = 6.3 crest milliamperes.

Reasonably Safe Direct Currents

The following d-c release currents were taken from reference 2:

Men, corrected average = 76.1 d-c milliamperes
99.5 percentile = 62.0 d-c milliamperes
Women, 99.5 percentile = 41.0 d-c milliamperes

Using the reasoning of the preceding paragraph, the reasonably safe direct current for healthy children was computed as $0.50 \times 62.0 = 31.0$ d-c milliamperes. These values were plotted on the horizontal axis of Figure 2 to fix the lower limits of the curves. At the conclusion of the a-c let-go-current tests, the two boys used in this investigation released the following direct currents easily and without comment. Higher values were not attempted:

Age 9 years 3 months . . 15 d-c milliamperes
Age 10 years 11 months . . . . . 26 d-c milliamperes

141 Per Cent Offset-Wave-Form Let-Go-Current Tests

In these tests 60-cycle sine-wave alternating current was superimposed on direct current to produce the current wave forms shown in Figure 1C. The proper proportion of the alternating current to direct current was maintained by connecting an ordinary d-c milliammeter in series with a shunt to which was connected a General Radio type 726A vacuum-tube voltmeter. Adjustments were made so that the d-c milliamperes were always equal to the root-mean-square a-c milliamperes, resulting in a wave having a ripple equal to

$$\text{Ripple} = \frac{\text{crest a-c milliamperes}}{\text{average milliamperes}} = \frac{\sqrt{2}\ \text{rms milliamperes}}{\text{d-c milliamperes}} = 1.41$$

Experimental values and analysis are given in Table II, and the corresponding deviation curves are shown in Figures 5 and 6. Three determinations of let-go currents were made; one test with the wire electrode negative, one with the wire electrode positive, and one test with commercial 60-cycle sine wave to serve as a control. The three tests were conducted on the same afternoon to obtain comparable results. The sequence of the tests was alternated among the subjects to randomize the effects of fatigue. It will be noted that the experimental points fell closely about the 60-cycle standard-deviation curve. This was interpreted to mean that a sufficient number of subjects had been used to permit predictions of acceptable accuracy to be made for a large group of subjects. The corrected mean of the sample was computed from equation 2, reference 2. Equations 3 and 4, reference 2, were then used to predict reasonably safe currents for men and women. The reasonably safe current for children was taken as 50 per cent of the safe value for men, using the data obtained with the wire electrode negative to give conservative results. Experimental and computed points for the wire negative were then plotted on Figure 2 to assist in locating the mean and safe let-go current curves.

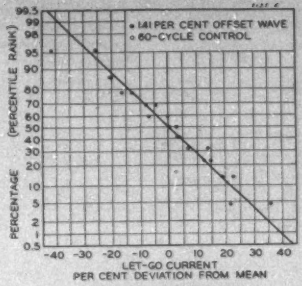


Figure 5. 141 per cent offset-wave let-go-current deviation curve

Hand electrode negative

50 Per Cent Offset-Wave-Form Let-Go-Current Tests

A similar procedure was used to determine the let-go currents for a wave having 50 per cent a-c ripple. For these tests the proportion of alternating current to direct current was maintained so that the d-c milliammeter read exactly twice the crest a-c milliamperes. Experimental values and analyses are given in Table III and the corresponding deviation curves in Figures 7 and 8.

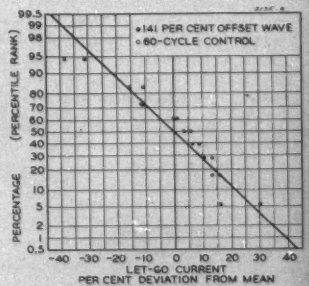


Figure 6. 141 per cent offset-wave let-go-current deviation curve

Hand electrode positive

Although the experimental points (especially the 60-cycle control points) did not follow the 60-cycle standard-deviation curve as closely as desired, this was the best that could be done with the available data. At the beginning of the investigation some six years ago, it was planned to obtain values for at least 25 subjects for each test in order to eliminate possible criticism due to deriving conclusions from

Table III. Let-Go Currents—Sine-Wave and 50 Per Cent Offset-Wave Tests

Hand Electrode Positive			Hand Electrode Negative		
Subject No.	Sine-Wave Control 60-Cycle (Rms Milliamperes)	Offset-Wave A-C Component (Rms Milliamperes)	Subject No.	Sine-Wave Control 60-Cycle (Rms Milliamperes)	Offset-Wave A-C Component (Rms Milliamperes)
123	17.5	7.2	93	17.2	6.0
135	19.3	7.7	123	17.5	6.3
93	17.2	7.9	132	18.3	6.8
82	16.2	8.3	125	19.3	7.1
129	15.1	8.4	129	15.1	7.8
132	18.3	8.6	130	17.6	7.8
125	16.7	8.6	82	16.2	8.1
124	21.5	9.2	124	21.5	8.3
130	17.6	9.3	135	16.7	8.6
134	19.8	9.5	134	19.8	9.8
Mean:	17.92	8.47		17.92	7.66
Corrected mean:					
A-c crest	$\sqrt{2} \times 8.47 \times 15.87/17.92 = 10.61$ milliamperes			$\sqrt{2} \times 7.66 \times 15.87/17.92 = 9.60$ milliamperes (equation 2, reference 2)	
D-c average	$2 \times 10.61 = 21.22$ milliamperes			$2 \times 9.60 = 19.20$ milliamperes (see Figure 1B)	
99½ percentile:					
A-c crest men	$10.61(1 - 0.432) = 6.02$ milliamperes			$9.60(1 - 0.432) = 5.45$ milliamperes	
D-c average men	$21.22(1 - 0.432) = 12.05$ milliamperes			$19.20(1 - 0.432) = 10.92$ milliamperes (equation 3, reference 2)	
A-c crest children	$0.5 \times 6.02 = 3.0$ milliamperes			$0.5 \times 5.45 = 2.7$ milliamperes	
D-c average children	$0.5 \times 12.05 = 6.0$ milliamperes			$0.5 \times 10.92 = 5.5$ milliamperes	
A-c crest women	$6.02 \times 10.5/15.87 = 4.0$ milliamperes			$5.45 \times 10.5/15.87 = 3.6$ milliamperes	
D-c average women	$12.03 \times 10.5/15.87 = 8.0$ milliamperes			$10.92 \times 10.5/15.87 = 7.2$ milliamperes (equation 4, reference 2)	
Polarity effect	$9.60/10.61 = 0.90$				

Table IV. Let-Go Currents—Sine-Wave and Six Per Cent Offset-Wave Tests

Subject No.	Hand Electrode Negative: Sine-Wave Control 60-Cycle (Rms Milliamperes)	Offset-Wave Components: A-C Rms Milliamperes	Offset-Wave Components: D-C Average Milliamperes	Remarks
45	16.2	2.3	53	Let-go current
134	15.1	2.9	70	Limit of endurance
140	15.8	3.2	73	Limit of endurance
Mean:	15.7	2.8	65.3	

A-c crest = $2.8\sqrt{2} = 3.96$

Per cent ripple = $\frac{3.96}{65.3} = 0.06$

insufficient data. Conclusions based on available data are therefore submitted, subject to slight adjustments, should this be found desirable when conditions permit resumption of the project. Experimental research was stopped when the nation became involved in the war, and it will not be resumed for the duration.

Six Per Cent Offset-Wave-Form Let-Go-Current Tests

The results of let-go current tests made with a composite wave having a ratio of crest alternating current to direct current equal to 0.06 are given in Table IV. This was the last test made before the experiments were terminated, and only three subjects were used. Three values are too few in number to warrant drawing conclusions, and the point representing this test was omitted from Figure 2.

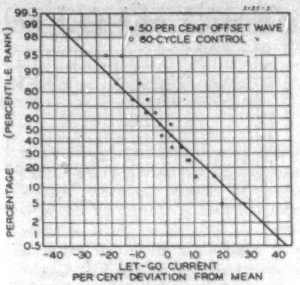


Figure 7. 50 per cent offset-wave let-go-current deviation curve

Hand electrode negative

However, if the point representing the average for the group is inserted on Figure 2, it will be found to be well above the mean curve. This is consistent with the conjecture that the lower end of the curve, which was determined from tests using pure direct current, is well on the side of safety. These data are instructive, since one of the three subjects reached his let-go limit while the other two did not. Although two subjects could still release the electrode, they refused higher currents because of the severity of the shock at the instant of releasing the electrode. This is the only case where let-go currents and release currents were encountered in the same test. These observations stress the importance of considering the alternating component, regardless of how small it may be in comparison to the direct component, when studying shock hazards. Sensations produced by the filtered output of a *B* eliminator, in which the a-c ripple was so small that it was thought negligible, were much more painful than the same current obtained from a battery.

Table V. Let-Go Currents—Sine-Wave and Rectified-Half-Wave Tests

Subject No.	Hand Electrode Positive: Sine-Wave Control 60-Cycle (Rms Milliamperes)	Rectified Half-Wave (Average Milliamperes)
45	18.5	6.7
77	14.4	7.0
126	17.8	8.5
129	16.9	8.6
130	18.5	8.9
125	17.3	9.1
132	15.6	9.1
124	17.3	9.5
37	20.9	9.8
21	25.1	10.0
93	17.1	10.1
Mean:	18.13	8.84

Determination of polarity correction factor
From Table II 0.85
From Table III 0.90
Mean 0.875

Corrected mean:

D-c average men: $8.84 \times 15.87/18.13 = 7.74$ milliamperes, hand electrode positive (equation 2, reference 2)

A-c crest men: $2.14 \times 7.74 = 16.57$ milliamperes, hand electrode positive (see Figure 1D)

D-c average men: $0.875 \times 7.74 = 6.77$ milliamperes, hand electrode negative (using polarity correction factor = 0.875)

A-c crest men: $2.14 \times 6.77 = 14.49$ milliamperes, hand electrode negative (see Figure 1D)

99½ percentile:

A-c crest men: $14.49(1-0.432) = 8.22$ milliamperes, hand electrode negative

D-c average men: $6.77(1-0.432) = 3.85$ milliamperes, hand electrode negative (equation 3, reference 2)

A-c crest children: $0.5 \times 8.22 = 4.1$ milliamperes, hand electrode negative

D-c average children: $0.5 \times 3.85 = 1.9$ milliamperes, hand electrode negative

A-c crest women: $8.22 \times 10.5/15.87 = 5.4$ milliamperes, hand electrode negative

D-c average women: $3.85 \times 10.5/15.87 = 2.5$ milliamperes, hand electrode negative (equation 4, reference 2)

Table VI. Sine Wave and Rectified Full-Wave Tests

Subject No.	Hand Electrode Positive: Sine-Wave Control 60 Cycle (Rms Milliamperes)	Rectified Full-Wave (Average Milliamperes)
82	12.2	15.0
128	13.5	16.0
123	16.2	18.5
45	16.2	18.5
131	16.8	19.0
132	16.1	19.8
129	13.5	20.2
122	19.8	21.0
124	18.2	21.5
130	14.6	22.1
125	17.3	23.4
109	20.0	26.4
37	20.9	26.4
105	23.0	27.5
Mean:	17.02	21.09

Corrected mean:

D-c average men: $21.99 \times 15.87/17.02 = 19.66$ milliamperes, hand electrode positive (equation 2, reference 2)

A-c crest men: $0.571 \times 19.66 = 11.22$ milliamperes (see Figure 1E)

D-c average men: $0.875 \times 19.66 = 17.20$ milliamperes, hand electrode negative (using polarity correction factor = 0.875)

A-c crest men: $0.571 \times 17.20 = 9.82$ milliamperes, hand electrode negative (see Figure 1E)

99½ percentile:

A-c crest men: $9.82(1-0.432) = 5.58$ milliamperes, hand electrode negative

D-c average men: $17.20(1-0.432) = 9.77$ milliamperes, hand electrode negative (equation 3, reference 2)

A-c crest children: $0.5 \times 5.58 = 2.8$ milliamperes, hand electrode negative

D-c average children: $0.5 \times 9.77 = 4.9$ milliamperes, hand electrode negative

A-c crest women: $5.58 \times 10.5/15.87 = 3.7$ milliamperes, hand electrode negative

D-c average women: $9.77 \times 10.5/15.87 = 6.5$ milliamperes, hand electrode negative (equation 4, reference 2)

Rectified Full- and Half-Wave Let-Go-Current Tests

Let-go current tests were conducted, using the output of a single-phase mercury-arc rectifier. The results obtained using one anode are given in Table V and Figure 9. Similar data obtained for both anodes are given in Table VI and Figure 10. These tests were conducted with the hand electrode positive. Sixty-cycle sine-wave let-go tests were also conducted to serve as a control for computing the response for a large group, as previously discussed.

It was found that the sensations produced by the current were more painful and the let-go current was less when the hand electrode was negative in comparison to tests made with the hand electrode positive. The tests using the rectified waves were conducted with the hand electrode positive, and it was necessary to determine a correction for polarity, in order to compare the points representing these tests with the preceding data. The effect of polarity was determined from the 141 per cent and the 50 per cent offset-wave tests. A polarity correction factor was taken equal to the ratio (mean let-go current, hand electrode negative) ÷ (mean let-go current, hand electrode positive). The average ratio obtained from these two tests was taken as the polarity correction factor = 0.875. This factor was used in the analysis of the data of Tables V and VI, and the points determined thereby were given due consideration in locating the curves of Figure 2.

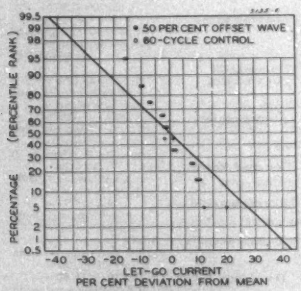


Figure 8. 50 per cent offset-wave let-go-current deviation curve

Hand electrode positive

The polarity effect, which was found to decrease the average let-go currents 12½ per cent when the hand electrode was negative, may have value from a safety standpoint. The decrease in both the sensations and the shock hazard for a given current when the hand electrode is positive may be helpful in arriving at a decision whether to ground the positive or the negative side of a circuit.*

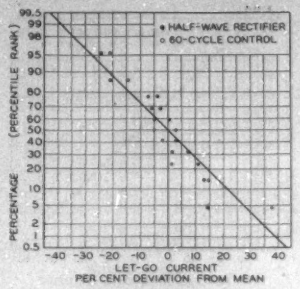


Figure 9. Rectified half-wave let-go-current deviation curve

Hand electrode positive

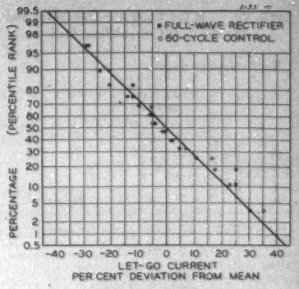


Figure 10. Rectified full-wave let-go-current deviation curve

Hand electrode positive

As can be seen from inspection of Figure 10, the experimental points for the full-wave-rectifier test followed the 60-cycle standard-deviation curve closely. In comparison, the points for the half-wave-rectifier test were somewhat more scattered about the deviation curve (see Figure 9). It should be noted that the scattering about the deviation curve was about the same for both the wave form under investigation and the 60-cycle control. The scattering was explained as due to the limited number of subjects tested rather than to suggesting a different response for rectified half-wave currents. It is believed that data from a larger group of subjects would have reduced the discrepancies and resulted in the points following the 60-cycle deviation curve as closely as that found for the other tests.

Smooth curves were drawn through the computed points (wire negative) to give the curves of Figure 2. Several other attempts were made to analyze the data, but for each case tried at least some of the computed points failed to follow a common curve. Points obtained from the analysis described in the foregoing paragraphs closely follow the same curve, and for this reason it is believed that the procedure is sufficiently general to permit predicting reasonably safe currents with acceptable accuracy for wave shapes similar as well as those actually used in the experiments. Although one must use caution when arriving at conclusions, the good agreement between the experimental points and the theory suggest that the analysis should be valid for predictions involving complex or composite waves containing a-c components and d-c components in the proportions likely to be met on commercial apparatus or associated circuits. As previously discussed, it is believed that errors due to wave forms containing high-frequency components should be on the safe side, and the resulting currents should be on the side of safety.

* It is well known to physiologists that during passage of direct current through a nerve the regions in the neighborhood of the electrodes are altered with respect to

1. Sensitivity to stimulation.
2. Ability to conduct nerve impulses.

The negative region becomes more sensitive and a better conductor.

References

1. Electric Shock, Charles F. Dalziel, John B. Lagen, Joe L. Thurston. AIEE Transactions, volume 60, 1941, pages 1073–9; discussion pages 1295–7.

2. Effect of Frequency on Let-Go Currents, Charles F. Dalziel, Eric Ogden, Curtis E. Abbott, AIEE Transactions, volume 62, 1943, December section, pages 745–50.

Effect of Frequency on Let-Go Currents

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Synopsis: This paper on electric shock covers the subject of sine-wave let-go currents for both men and women and contains an analysis which permits improved accuracy in predicting the response for large groups based on experiments made on a relatively small number of subjects. It should be of especial interest to persons who have had accidents in which they barely escaped "freezing" to an electrified conductor and also to those interested in electrical safety. The range of frequencies covered is from 5 to 10,000 cycles and also direct current. The paper is the most comprehensive treatment of the subject yet published as the analysis permits predicting currents of a specified degree of safety for both men and women for this wide frequency range.

THIS paper presents the results of a study to determine the effect of frequency on let-go currents made on 134 men and 28 women at the University of California. Let-go currents are important, because it has been found that an individual can withstand, with no ill aftereffects, repeated exposure to his let-go current for at least the time required for him to release the conductor. Larger currents are dangerous, because release from the circuit during accidental contact is problematical. A reasonably safe current for normal men and women is defined as the let-go current for 99½ per cent of a large group. A knowledge of let-go currents is important for the formation of safety codes, for explaining accidents, and for the design of electrical devices with exposed electrodes.

The majority of the data was presented in a preliminary report before the Institute in 1941.[1] The number of male subjects for the 60-cycle test now totals 134, the data on females are new, and an improved analysis is disclosed. Use of the new analysis permits improved accuracy in predicting results for a large group from tests made on a small but representative sample. The paper includes an example in which the method is used to predict probable let-go currents for all normal men and women for a frequency range from 5 to 5,000 cycles. Estimates are given for 10,000 cycles and also for direct current.

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Determination of Let-Go Currents

An individual's let-go current is defined as the maximum current he can tolerate when holding a copper conductor in one hand and yet let go of the conductor by using muscles directly affected by that current. No material changes in experimental procedure, safety precautions, selection of subjects, or equipment were found to be necessary, and, in general, the experiments were continued as described in the preliminary report. The following résumé is included for convenience. The subjects held and then released a test electrode consisting of a number 6 copper wire, and the circuit was completed by placing the other hand or foot on a flat brass plate, or by clamping a conducting band lined with moist cloth firmly on the upper arm. After one or two preliminary trials to accustom the subject to the sensations and muscular contractions produced by the current, the current was increased to a certain value and the subject was commanded to let go of the wire. If he succeeded, the test was repeated at a slightly higher value. If he failed, a lower current was used, and the values were again increased until the subject could no longer release the test electrode. The end point was checked by several trials. The agreement between those trials was within about two to five per cent, and the highest value was taken as the individual's let-go value in order to eliminate the effects of fatigue.

The tests reported here were conducted with hands wet with a common saltwater solution to secure uniform conditions and to reduce the sensation of burning caused by high current densities at tender spots and at the instant of releasing the electrode. Other tests were made with dry hands, hands moist from perspiration, and hands dripping wet from weak acid solutions. The effect of the size of the electrodes was also investigated. As reported previously, the location of the indifferent electrode, the moisture conditions at the points of contact, and the size of the electrodes had no appreciable effect on an individual's let-go current. It is believed that conclusions based on tests using the wet copper electrode may be used to predict reasonably safe electric currents with an accuracy sufficient for most practical purposes.

There was considerable variation in an individual's value on succeeding trials, the trend usually being toward higher values. Therefore the largest current released on the *first* test on any frequency was taken as the let-go current for that frequency. This was done to include the element of surprise to as great an extent as possible and to give conservative results. Psychological factors, especially fear and competitive spirit, were the most important causes for the variations. Physiological factors also played an important part, but so far their exact mechanism remains unknown. It seemed that let-go currents in both sexes were related to the muscular development of the wrist and forearm. Husky subjects having low let-go values could almost invariably be persuaded (or heckled by other subjects) to continue the test until their values were in line with others of similar physique. Although attempts were made to quantitate this relationship by correlating let-go currents with the strength of grip and with forearm and wrist diameters, the results were inconclusive. Perhaps this was because of the narrow range and lack of precision involved in the physiological measurements; moreover, forearm and wrist diameters are determined to an uncertain degree by fat and bone as well as by muscular tissue.

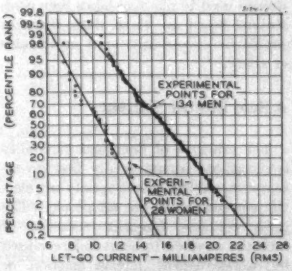

Figure 1. 60-cycle let-go-current distribution curves for men and women

Electric currents of a specified degree of safety for normal men or women may be obtained directly from the curves

Sixty-cycle let-go currents were meas-

ured on 27 additional women, bringing the total to 28. The subjects ranged in age from the late teens to the early twenties, were light in stature, and obviously not accustomed to hard physical work, and their forearm muscles were not particularly well developed. Although the women volunteered freely for the tests, it proved impossible to develop enthusiasm or any degree of competition at high currents. The results are probably representative for the sedentary type; however, from observation of the reactions of subjects having the greatest muscular development, it is likely that the values were considerably lower than those which would have been obtained, had a typical group of mature healthy women used to physical labor been used. Results based on these data therefore should be conservative and on the side of safety.

A Safe Electric Current

The principle of biological variability is recognized so universally that no attempt should be made to specify any electric current as safe for all people. The press contains frequent accounts of fatalities ascribed to heart failure caused by overexcitement, intense emotion, or shock (shock of injury, *not* electric shock). Some of the subjects volunteering for these tests became frightened and trembled all over; some even complained of pain when holding the test electrode before the current was turned on. Although these persons were not used in the experiments, the experiences dramatically illustrated the possibility that a person with a diseased heart might succumb from any contact, or even the fear of contact, with an electric circuit. This possibility must be recognized, and an occasional death is to be expected as a result of casual contact involving electric currents known to be harmless to the great majority of healthy individuals.

Quite aside from determining an absolutely safe electric current for all human beings is the practical problem of determining a current which would be reasonably safe for most normal healthy adult men and women. In certain cases, economics or special applications may necessitate the use of current values which are hazardous to only a small percentage of a large group. This is particularly important at the present time, because of the widespread use of electric devices having exposed electrodes.[2,3]

Several factors must be considered in deciding what constitutes a reasonably safe electric current. The victim of a severe accidental electric shock can often release himself by using muscles little affected by the current. The muscular reactions produced by the current may tend to break the circuit rather than to improve it, or loss of balance may free the victim. However, it is doubtful if any of these methods would be of avail when contact is established by gripping an electrified conductor so that the path of the current was across the body. The hazard due to electric shock depends upon several factors, the most important being the magnitude of the current, the current pathway through the body, the time of contact, and the physical condition of the victim.

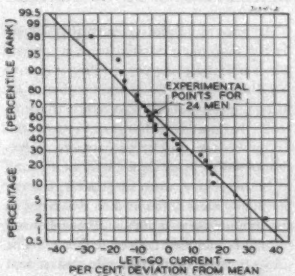

Figure 2. Five-cycle deviation curve for men

Conclusions regarding reasonably safe electric currents were based on the factors mentioned in the preceding paragraphs, together with the results of carefully conducted experiments made on a total of approximately 250 men and 28 women, and involved several thousand individual tests. Without a single exception, it was found that an individual could withstand, with no ill aftereffects, repeated exposure to his let-go current for at least the time required for him to release the conductor. The current pathway for the majority of the tests was between the hands. A few experiments were made with current pathway between one hand and one or both feet; in other tests the pathway was between the hand and an arm band.[2,3]

It is the authors' studied opinion that, for most practical purposes, the maximum electric current which is safe for an individual is the greatest current he can release by using muscles directly affected by that current. From this, it was concluded that a reasonably safe electric current for most normal healthy physically fit adult men and women is the let-go current for 99½ per cent of a large group. Numerical determination of reasonably safe currents from the let-go current tests will be discussed later at an appropriate point in the text.

Analysis of Let-Go Currents

Let-go currents were obtained for groups of male subjects ranging in number from 25 to 134 using sine-wave alternating currents from 5 to 10,000 cycles and also direct current. The let-go currents for each test were then plotted on probability cross-section paper, and the straight line governed by the majority of the points was drawn to obtain the normal distribution curve for the sample. An advantage of this method is that points obviously not conforming to the sample may be disregarded by inspection. The procedure is illustrated in Figure 1 which gives the 60-cycle let-go-current distribution curves for 134 men and 28 women. Distribution curves for the other frefrequencies were similar, except for the

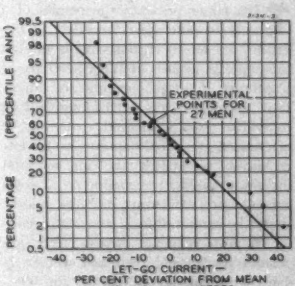

Figure 3. Ten-cycle deviation curve for men

current scale or the slope of the distribution curve.

It was found that, when let-go currents were plotted as per cent deviations from the mean of any test, the slope of all the resulting straight lines was the same. This was true for both men and women on the 60-cycle tests and for other tests from 5 to 5,000 cycles. Deviation curves for the 60-cycle tests are given in Figures 5 and 5A. Since only a small number of subjects was used for other than the 134-men 60-cycle test, the straight line response of Figure 5 was drawn on each curve as the probable response for the other frequencies also. Within the range of 5 to 5,000 cycles, the straight line representing the 60-cycle response was the best line that could be drawn through the majority of the points (see Figures 2 to 10 inclusive). The fact that let-go current values follow the same deviation curve may be illustrated in a rather strik-

ing manner if all the points (excluding the 60-cycle values, to avoid confusion) are plotted on the same curve sheet. The wide discrepancies of one or two points from the deviation curves were due to the relatively small number of subjects used. The reason that let-go currents follow the same curve for this range of frequencies may be related to the similarity of the physiological phenomena, which were characterized by painful muscular contractions. Outside of this frequency range, sensations of heat predominate. Strictly comparable measurements are not possible for direct current.

In previous studies, the mean of a test was taken as the most reliable measure for the sample, and the accuracy of prediction was chiefly dependent upon the number of subjects used for a particular test. Improved accuracy for small samples results from plotting the data as percentage deviations from the mean of the sample and comparing the response with the slope of the 134-men 60-cycle deviation curve of Figure 5. In the five-cycle test, shown in Figure 2, two points deviated from the rest of the data sufficiently to suggest that they should be discarded. Accordingly, the points were recomputed after the data from these two subjects had been rejected, leaving a total of 24 points. Such rejection was not found to be necessary in the other tests.

Predictions for any percentile rank are obtained from

Percentile rank = mean of sample ± deviation from mean × mean of sample

or

Percentile rank = mean of sample (1 ± deviation from mean) (1)

It is evident that the accuracy of prediction depends to a large extent upon the accuracy of the 134-men 60-cycle deviation curve and upon the subjects being a true random sample of the population. The data upon which this curve was constructed were obtained from carefully conducted tests made during a six-year period. Although care was taken to obtain only subjects in good physical condition, they were not selected especially with respect to age, weight, or muscular development. They represented a wide variety of normal men, with an age range of from 21 to 46. The close agreement between the 134 points and resulting straight line indicates that the response actually followed a normal distribution. This is exactly what should have been observed, had an infinite sample been tested. This close agreement is presented to substantiate the conclusion that a sufficient number of subjects has been examined to permit determination of the response of a large sample. Proceeding to the limit, it is assumed that a sufficient number of subjects has been tested to obtain the representative response of all normal men with an accuracy sufficient for engineering purposes.

An important factor controlling the accuracy of predictions for other tests is the necessity of procuring a representative sample. It is entirely possible that any small sample may have a mean considerably above or below that of an average sample, irrespective of agreement with the standard deviation curve. This is particularly important in experiments such as this, because it was usually found that let-go currents on the same frequency had a tendency to increase as the number of tests increased. This was attributed to the subject's becoming accustomed to the ordeal. Let-go-current tests should be conducted for the given test conditions and also on sine-wave 60 cycles to serve as a control. The order of the tests among the subjects should be changed frequently to randomize effects of fatigue.

The corrected mean, that is, the mean for an infinite sample equals

$$\text{Corrected mean of sample} = \frac{\text{Mean 60-cycle let-go current of all men}}{\text{Mean 60-cycle let-go current of sample}} \times \text{mean of sample for given test conditions}$$

or

$$\text{Corrected mean of sample} = \frac{15.87}{\text{60-cycle control}} \times \text{mean of sample} \quad (2)$$

The percentile rank for an infinite group is obtained from

Percentile rank = corrected mean of sample × (1 ± deviation from mean) (3)

For example, the $^1/_2$ or $99^1/_2$ per cent response for any frequency between 5 and 5,000 cycles is given by

Deviation from the mean for $^1/_2$ per cent or $99^1/_2$ per cent = ±0.432 (from Figure 5)

$^1/_2$ or $99^1/_2$ percentile rank = corrected mean of sample × (1 ± 0.432)

Figure 14 shows the effect of frequency on let-go currents. Significant data are included in Table I to illustrate the method of analysis. At the time these data were obtained, no 60-cycle control was taken, but the subject's mean 60-cycle let-go current was used to give an

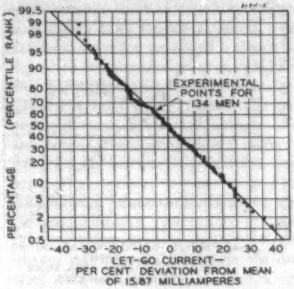

Figure 5. 60-cycle deviation curve for men

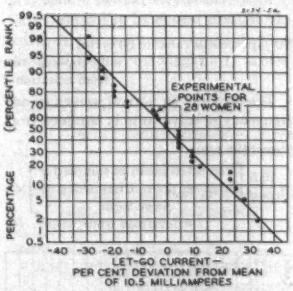

Figure 5A. 60-cycle deviation curve for women

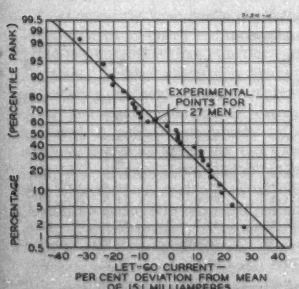

Figure 4. 25-cycle deviation curve for men

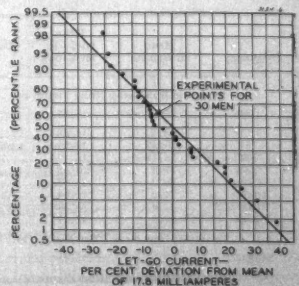

Figure 6. 180-cycle deviation curve for men

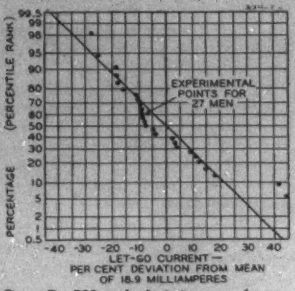
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 27 MEN
-40 -30 -20 -10 0 10 20 30 40
— LET-GO CURRENT —
PER CENT DEVIATION FROM MEAN OF 18.9 MILLIAMPERES

Figure 7. 500-cycle deviation curve for men

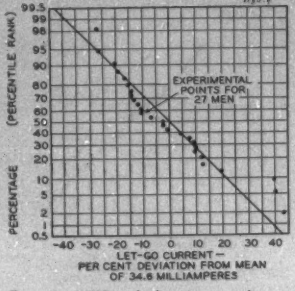
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 27 MEN
-40 -30 -20 -10 0 10 20 30 40
— LET-GO CURRENT —
PER CENT DEVIATION FROM MEAN OF 34.6 MILLIAMPERES

Figure 9. 2,500-cycle deviation curve for men

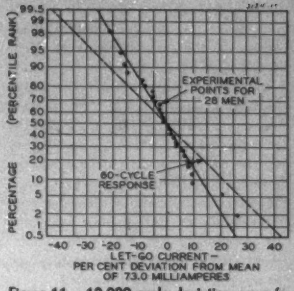
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 28 MEN
60-CYCLE RESPONSE
-40 -30 -20 -10 0 10 20 30 40
— LET-GO CURRENT —
PER CENT DEVIATION FROM MEAN OF 73.0 MILLIAMPERES

Figure 11. 10,000-cycle deviation curve for men

approximate correction. Computed points lie close to smooth curves, the data appear to be consistent, and the curves should represent the response for a large group of normal men. The curves read from below upwards illustrate the probability that the current they represent will be dangerous. As previously discussed, a reasonably safe current for normal male adults is proposed as that represented by the lowest curve which indicates values safe for at least 99½ per cent of the group tested.

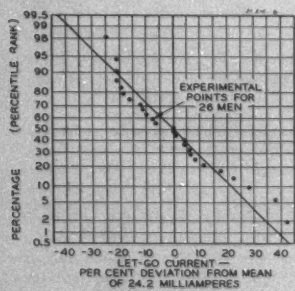
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 26 MEN
-40 -30 -20 -10 0 10 20 30 40
— LET-GO CURRENT —
PER CENT DEVIATION FROM MEAN OF 24.2 MILLIAMPERES

Figure 8. 1,000-cycle deviation curve for men

A safe current for normal women (Figure 5A) was computed as follows:

99½ percentile rank for 60 cycles
$= 10.5 \quad (1 - 0.432) = 6.0$ milliamperes rms from equation 1

The response for normal women on any frequency or wave form is obtained from

$$\text{Percentile rank} = \frac{10.5}{15.87}\left[\begin{array}{c}\text{corrected mean of sample for}\\ \text{men on desired frequency or}\\ \text{wave form}\end{array}\right] \times (1 + \text{deviation from mean}) \quad (4)$$

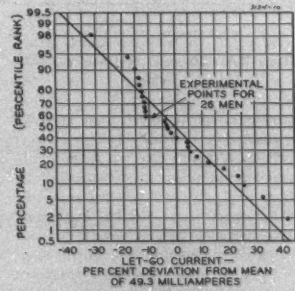
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 26 MEN
-40 -30 -20 -10 0 10 20 30 40
— LET-GO CURRENT —
PER CENT DEVIATION FROM MEAN OF 49.3 MILLIAMPERES

Figure 10. 5,000-cycle deviation curve for men

from which it is apparent that the let-go current for women is equal to 10.5 + 15.87 = 66 per cent of the corresponding percentile values for men. Hence the safe current for normal women is equal to approximately two-thirds of the bottom curve of Figure 14. This procedure is predicated on the assumption that the physiological phenomena associated with let-go currents for both normal men and women are similar and that the ratio of the let-go currents is the same at all fre-

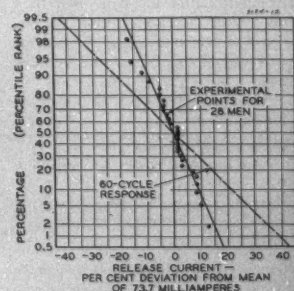
(PERCENTILE RANK)
PERCENTAGE
EXPERIMENTAL POINTS FOR 28 MEN
60-CYCLE RESPONSE
-40 -30 -20 -10 0 10 20 30 40
— RELEASE CURRENT —
PER CENT DEVIATION FROM MEAN OF 73.7 MILLIAMPERES

Figure 12. D-c deviation curve for men

Table I. Let-Go Currents for Men Versus Frequency

Frequency	Mean of Sample	Mean 60-Cycle for Group	Corrected Mean	Percentile Rank ½	1	25	50	75	99	99½
Deviation from mean (from Figure 5)				0.432	0.390	0.115	0.00	−0.115	−0.390	−0.432
60	15.87	15.87	15.87	22.7	22.1	17.7	15.87	14.0	9.7	9.0
5	23.4	14.56	25.5	36.5	35.5	28.4	25.5	22.6	15.5	14.5
10	16.27	14.94	17.3	24.8	24.0	19.3	17.3	15.3	10.5	9.8
25	15.14	15.11	15.9	22.7	22.1	17.7	15.9	14.1	9.7	9.1
180	17.8	15.42	18.3	26.2	25.4	20.4	18.3	16.2	11.2	10.4
500	18.9	15.53	19.3	27.6	26.8	21.5	19.3	17.1	11.8	11.0
1,000	24.2	15.84	24.2	34.7	33.7	27.0	24.2	21.5	14.8	13.7
2,500	34.6	15.87	35.2	50.4	48.9	39.3	35.2	31.2	21.5	20.0
5,000	49.3	16.17	51.6	73.9	71.7	57.8	51.6	45.7	31.5	29.3
Deviation from mean (from Figure 11)				0.260	0.234	0.068	0.00	−0.068	−0.234	−0.260
10,000	73.0	15.48	74.8	94.3	92.3	79.9	74.8	69.7	57.3	55.3
Deviation from mean (from Figure 12)				0.185	0.167	0.049	0.00	−0.049	−0.167	−0.185
D-c	73.7	15.37	76.1	90.3	88.9	79.9	76.1	72.5	63.5	62.1

quencies. It is believed that discrepancies due to sex differences are too small to affect practical conclusions with regard to electrical safety.

Sensations at the higher frequencies, especially those on 10,000 cycles or higher, were less painful, and the severity of the muscular contractions was less than that on the lower frequencies. Alarming sensations of internal heating were produced, muscular control was sluggish, and the time to let go the conductor increased considerably. These differences in physiological phenomena were associated with a deviation curve having a greater slope (see Figure 11). A straight line was drawn through the majority of the points to determine the deviation curve. The

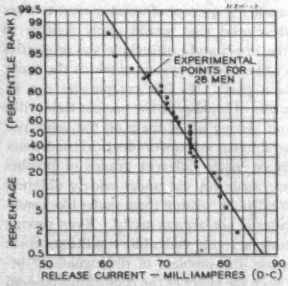

Figure 13. D-c release-current distribution curve for men

60-cycle response was sketched on the curve for comparison. Although the experimental points fell close to the deviation curve, the accuracy of predicting the response for a large group is less than that for the lower frequencies, since it depends upon the accuracy of the small amount of data available on this frequency alone. However, the data were analyzed in a manner similar to that used for the other frequencies and are included in Table I.

Tests on steady or gradually increasing direct currents produced sensations of internal heating rather than muscular contractions. Sudden changes in current magnitudes produced muscular contractions, and interruption of the current produced a very severe shock. The muscular reactions when the test electrode was released at the higher values were objectionable, and sooner or later all subjects declined to take more punishment. Tests were made on 28 men, and in each case little difficulty was experienced in releasing the electrode. The maximum a subject would take and release was termed the release current. It represents the limit of voluntary endurance rather than the let-go limit. The deviation curve for these tests is shown in Figure 12 and the release curve in Figure 13. At the conclusion of the 60-cycle let-go-current tests on 27 women, the experiments were terminated with one or two release tests using direct current. After one or two preliminary trials, the current was increased to a maximum of 35 milliamperes. Each subject released the electrode without complaint or difficulty. As previously reported,[1] a single woman was tested at the time the d-c tests were made on the men. She released 56 milliamperes direct current before refusing more.

The data for the d-c tests were analyzed in the same way as those for alternating currents but with less certain justification:

$$\text{Corrected mean of sample} = \frac{15.87}{15.37} \times 73.7$$

$$= 76.1 \text{ milliamperes direct current (from equation 2)}$$

Deviation from mean for 99½ percentile rank = −0.185 (from Figure 12)

99½ percentile rank for men
$= 76.1(1 - 0.185) = 62.0$ milliamperes direct current (from equation 3)

99½ percentile rank for women
$= \frac{10.5}{15.87} \times 76.1(1 - 0.185) = 41.0$ milliamperes direct current (from equation 4)

Based on the preceding data it is concluded that 62 and 41 milliamperes is a reasonably direct current for men and women respectively. Undoubtedly the maximum direct currents which are reasonably safe are in excess of these values. However, it would be unwise to suggest higher values as safe until additional experimental research is available.

Electrical Safety

Although current and *not* voltage is the proper criterion of shock intensity, the danger of accidental electric shock on commercial circuits is due almost entirely to the voltage of the circuit. Rather than that the layman or the public should be confused with a technical argument, he must be warned that all power circuits are dangerous. Many deaths are caused each year from accidental contacts with ordinary 120-volt lighting circuits. Contacts with house circuits are especially hazardous in moist or wet locations.

Conclusions

1. A reasonably safe electric current for normal healthy adults is the let-go current which 99½ per cent of a large group can release by using muscles directly affected by that current.

2. The reasonably safe 60-cycle current for most normal healthy adult men is about nine milliamperes; the reasonably safe 60-cycle current for most normal healthy adult women is about six milliamperes.

3. Let-go currents are affected by fre-

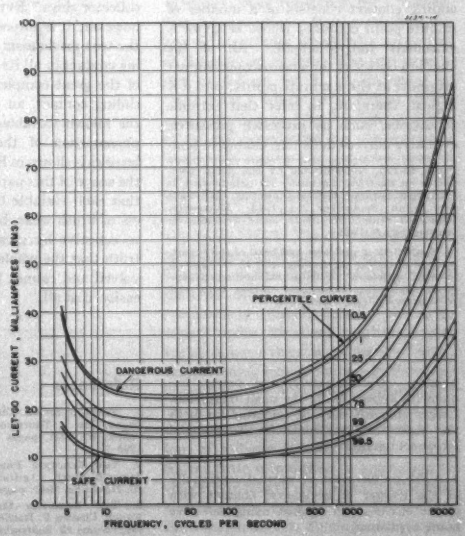

Figure 14. Sine-wave let-go current for men versus frequency

Current values become dangerous progressively to an increasing number of persons, as indicated by the percentile values on the right-hand side of the curves

Values for women are approximately 66 per cent of the current values shown on the curves

Some Measures of Electrical-Brush Disintegration

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Synopsis: So far as can be determined, the development of the concepts of wear resistance, wear resistivity, wear susceptance, and wear susceptibility as given in this paper is thoroughly new and original. These concepts are believed to be significant and useful tools that may further an understanding of the basic problems of sliding electrical contacts. For example, they offer means for making a valid comparison of brushes and brush materials insofar as wearing qualities are concerned. Moreover, they provide a clue to the proper consideration and evaluation of the large number of variables that are at work as brush disintegration takes place.

THE subject of wear itself is beset by many complications arising from the fact that the subject, at best, is largely statistical. It is accepted generally among authorities that there is no such thing as a perfect sliding contact, in which all sliding phenomena are continuous and uniform. Only grossly macroscopic data appear to be continuous, while data approaching microscopic proportions reveal discontinuities that are more or less periodic. It is conceded generally that a sliding contact consists of a number of minute point contacts, whose behavior is extremely individualistic. All of the characteristics of the macroscopic contact originate at these minute points; and it is logical, therefore, to infer that extreme conditions, such as excessive pressures, excessive current densities, excessive temperatures, and others, exist at these points. It is exceedingly difficult, therefore, to obtain a true picture of a sliding contact by means of the macroscopic data that are available to most experimenters and engineers. This paper is intended as an aid in the efforts to study sliding-contact materials by means of these macroscopic data.

Further complications arise when the term *wear* is applied to the undesirable destruction of all surfaces, whatever the manner in which the destruction may occur. The wear of shoe soles and heels, the wear of piston rings and cylinder walls, the wear of bearings, the wear of cutting edges, and many other types of wear, each involves a peculiar and, perhaps, unique combination of forces that provide the mechanism of wear. Therefore, when discussing wear, it is necessary to specify the particular kind that is being considered as well as the multitude of conditions that influence it.

This paper is intended to include only the type of wear that is encountered in the use of continuously sliding contacts, particularly the end wear of brushes riding on collector rings. Even in this simple case, however, it is impossible to comprehend the true mechanism of the wear of a sliding contact in all its details. As evidence of the great complexities that exist in a sliding contact, an abbreviated chart of the known variables that enter into the phenomenon of the wear of electrical brushes is shown in Figure 1. It is beyond the scope of this paper to discuss the part that each variable has in the whole process of brush wear, but it is not difficult to conceive by means of this chart the truth that the whole process is highly involved and cannot be disentangled very easily, if at all.

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Comparative

Nevertheless, it is desirable that electrical brushes be compared on the basis of relative wearing qualities as well as on the bases of contact resistance, current-carrying capacity, and other performance characteristics. V. P. Hessler has made a successful attempt within limitations to study the effects of various operating conditions upon electrical-brush wear as well as on brush contact drop.[1-3] He considered chiefly the effects of current density, ring speed, brush pressure, and relative humidity. That material has been distinctly useful in advancing toward a better understanding of basic relationships.

However, further progress could be made if a concept of wearing quality were developed that would apply strictly to the brush and not include the properties of the external system of which the brush is a part. No fair comparison can be made of brushes at the present time without testing all of them on the same test equipment and under identical conditions. Since many different grades of brushes are made for use under widely different conditions, testing them under like conditions is not always useful. Even though they be tested under like conditions, there is yet the problem of distinguishing between the effect of the conditions imposed on the interface by the whole sliding system, including the brush, and that of the structural properties of the contact faces. It is the intended purpose of this paper to develop a means whereby this distinction between the conditions responsible for producing wear and those responsible for resisting wear can be made. The latter conditions shall be implied in this paper by the term *wear resistance*.

The wear of a contact face is caused by the frictional forces that are present when sliding occurs. The structural characteristics of the contact specimen determine the resistance of the latter to wear when sliding occurs. Thus, the numerous variables of wear as evidenced by Figure 1 may be classified into two important groups—those which affect the frictional forces in one way or another, and those which affect the wear resistance of the contact specimen. The first group is associated with the whole sliding system while the second group concerns only the contact specimen itself. Of course, a particular variable may belong in both groups, as, for example, brush current. It is the means for measuring the effects of the second group on wear that are to be considered.

There is a philosophical truism that

quency. Unfortunately, the power frequencies appear to be the most dangerous. Larger currents may be tolerated for both the higher and the lower frequencies and for direct current.

4. The public must be warned continually of the danger of accidental contact with power circuits and against using defective home appliances.

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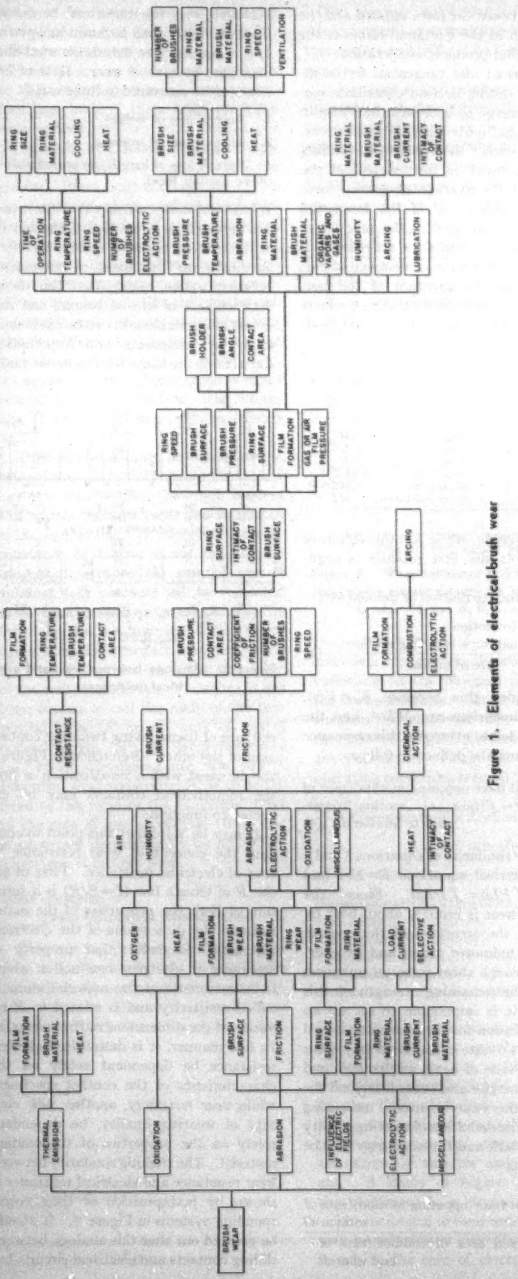

Figure 1. Elements of electrical-brush wear

asserts that the magnitude of any phenomenon is directly proportional to the magnitude of its cause and inversely proportional to the magnitude of that which resists or impedes the occurrence of the phemonenon. This truism is the basis for Ohm's law in the electrical system and for the analogous relationships in the magnetic and mechanical systems, respectively. It is proposed that it be applied to the phenomenon of wear. Since frictional force is the direct cause of wear, and the amount of wear is best measured as a time rate, it is suggested that that property whereby wear is resisted be defined so that the following relation will hold:

$$\text{Rate of wear} = \frac{\text{frictional force}}{\text{wear resistance}} \qquad (1)$$

It is believed that this equation represents a relationship that is just as fundamental and just as basic as is Ohm's law. In the light of this belief the efforts found in the literature to date to define wear resistance will be considered next.

It is interesting to note that the subject of wear has been studied from many different viewpoints, particularly in the field of metallurgy, and that many ingenious machines and other devices have been designed and built to test the wearing qualities of a variety of materials under controlled conditions that were intended to simulate actual working conditions. Only two papers have been found in the literature to date in which an attempt is made to define wear resistance by a mathematical expression. Neither of these expressions excludes wholly the properties of the external system. The first expression is defined by R. B. Freeman[4] as "unit wear," which he set equal to the expression obtained by "dividing the loss of weight experienced by the specimen during the run by the projected area of contact and the length of travel." This unit wear is measured in grams per square inch per foot and is expressed dimensionally as $ML^{-2}T^{-2}$. The chief disadvantage to this concept of unit wear is that it is a function of the density of the contact material being studied. Thus, if two specimens of differing densities should be tested under identical conditions and found to have the same volume of wear, the preceding expression would show the heavier specimen as having greater unit wear. It might be suggested that this definition be revised by substituting the loss of volume for the loss of weight. Such a ratio would then be equivalent to the ratio of length of end wear to the relative distance traveled by the contact faces and would be dimensionless. Both

definitions, however, are functions of the coefficient of friction and, therefore, do not provide a true comparison between different specimens for even the same contact area and contact travel. Thus, if one brush wears twice as much as another for the same ring travel and brush size, its unit of wear would be double that of the other, regardless of unequal surface conditions and other unlike conditions that influence the coefficient of friction.

The second expression that was found for wearing quality is defined by D. S. Clark and R. B. Freeman[3] as the energy required to overcome resistance to motion per unit volume of wear and is expressed dimensionally as $ML^{-1}T^{-1}$. The energy required to overcome resistance to motion, however, is a function of the coefficient of sliding friction as well as other properties that depend on the whole sliding system. The concepts of resistance to motion and of the energy required to overcome this resistance are treated later in this paper.

Table I

Electrical		Mechanical		Wear	
Inductance	L	Mass	M	Mass	M
Charge	Q	Length	L	Length	L
Time	T	Time	T	Time	T
Current	QT^{-1}	Velocity	LT^{-1}	Wear rate	LT^{-1}
Voltage	LQT^{-1}	Force	MLT^{-1}	Wear force	MLT^{-1}
Resistance	LT^{-1}	Resistance to motion	MT^{-1}	Wear resistance	MT^{-1}

Analytical

The frictional forces available for measurement are the tangential and normal forces, respectively, and the work done by (or against) each is the product of that force by the component of the relative motion of the contact member in the same (or opposite) direction of that force. Whenever force is applied to produce relative motion, the discrepancy between the applied force and the reactive forces due to the acceleration of the body is determined by frictional forces that produce heat and wear.

This statement may be represented by the following equation:

$$F = m\frac{dv}{dt} + K_d v \qquad (2)$$

where F is the applied force, m is the mass of the system to which the force is applied, v is the velocity of the system, and K_d is the resistance to motion.

This may be illustrated by the motion of a streetcar on tangent level track during the accelerating period with constant torque output from the motor. The difference between the force applied and the summation of the frictional forces is the net force that produces acceleration.

The normal and tangential forces involved in sliding friction contribute mechanical energy to both wear and heat in unknown and quite variable proportions. The total energy delivered to the sliding contact is equal to the integral of the product of the average tangential force times the differential of the tangential distance traveled and of the product of the normal force times the differential of the depth of the wear or distance of cut, measured in the direction of the normal force. For ordinary sliding contacts where gouging is absent, the second product is negligible, while for the action of cutting tools the first product is negligible.

If resistance to motion be defined as

$$\text{Resistance to motion} = \frac{\text{frictional force opposing motion}}{\text{rate of motion}} \qquad (3)$$

(or simplified this becomes $K_d = F/v$), then its dimensions are MT^{-1}, and the energy needed to overcome this resistance to motion may be defined as follows:

$$\int(\text{frictional force opposing motion})(\text{rate of motion})dt = \int(\text{rate of motion})^2(\text{resistance to motion})dt \qquad (4)$$

Note the similarity of equations 3 and 4 to the electrical equations $R = E/I$ and energy $= \int EIdt = \int I^2 Rdt$. Since the process of wear is brought about both by weakening the structure of the contact face to an unknown extent and by overcoming through sheer force an unknown part of the remaining strength of this structure, it is impossible to set up an exact expression for the energy absorbed by wear. To state it in another way, wear energy consists of heat, mechanical, and chemical energies and so far is beyond the reach of the experimenter's measuring devices. The definition of wearing quality given by Clark and Freeman may now be expressed as

$$\frac{\int(\text{frictional force opposing motion})(\text{rate of motion})dt}{\int(\text{projected area of contact})(\text{rate of end wear})dt}$$

Before wear resistance can be defined more explicitly than is shown in equation 1, it is necessary to determine what shall be meant by rate of wear. Rate of end wear can be measured in three ways:

1. Rate of loss of weight.
2. Rate of loss of volume.
3. Rate of loss of length (measured normal to the contact face).

It has been shown already that the rate of loss of weight is a function of the density of the contact material and is, therefore, unsuitable as the basis of comparison between unlike materials. The choice between rate of loss of volume and rate of loss of normal length can be made more easily by comparing two hypothetical contacts of the same homogeneous material, one of them having twice the contact area of the other. Reference to Figure 2 should assist with a visualization of how the hypothetical contacts may be expected to function.

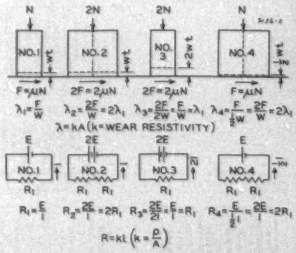

Figure 2. Analogy between wear and electrical resistances

It may be helpful at this point to compare the concept of wear resistance to that of electrical resistance. First of all, the R of Ohm's law ($I = E/R$) is a function of both the properties of the material and the dimensions of the electrical specimen. Secondly, that property of resistance to electrical conduction which is characteristic of the material alone is called resistivity and is related to R by means of the dimensions of the specimen. In like manner, it is desirable that wear resistance be dependent solely on the characteristics of the contact specimen, while *wear resistivity*, another new concept of wearing quality, be dependent solely on the properties of the contact material. The striking similarity between wear resistance and electrical resistance is shown by juxtaposition of their corresponding systems in Figure 2. It should be pointed out that this analogy between sliding contacts and electrical circuits has

the same limitation that all analogies have—that it can be carried too far, yielding some absurd results.

The requirement of identical conditions for these two hypothetical contacts implies that both of them must have the same normal pressure (say, pounds per square inch) and, hence, that the larger contact have twice the normal force of the smaller. Since both contacts are of the same material, their coefficients of friction (μ) may be assumed equal; therefore, the tangential force of the larger contact will be twice that of the smaller contact. Since the larger contact may be considered as two contacts like the smaller one fastened together, it may be assumed that both hypothetical contacts will have the same depth of end wear. Accordingly, the larger contact will lose twice as much volume as the smaller one. The limitation of this assumption will be treated later.

If the wear resistance be defined as the ratio of the tangential force to the rate of loss of normal length, the larger contact will appear to have twice the resistance of the smaller one. If, however, the wear resistance be defined as the ratio of the tangential force to the rate of loss of volume, both contacts will be indicated as having the same wear resistance. The first definition is a function of the properties of the whole contact specimen, while the second is a function of the properties of the contact material. Therefore, it has been chosen to call the ratio of the tangential force (F) to the rate of loss of normal length (W) the wear resistance (λ), whose dimensions are now MT^{-1}. Likewise, wear resistivity (k) is to be defined as the ratio of the tangential force to the rate of loss of volume (WA) and is expressed dimensionally as $ML^{-2}T^{-1}$. Therefore, it follows that

$$\text{Wear resistance} = \text{(wear resistivity) (contact area)} \quad (5)$$

This can be clarified readily by reference to the four cases illustrated in Figure 2, in which the expressions for wear resistance are given. The expressions for wear resistivity for these four cases are, respectively, as follows:

$$k_1 = \frac{F}{WA} = \frac{\lambda_1}{A}$$

$$k_2 = \frac{2F}{W \cdot 2A} = k_1 = \frac{\lambda_2}{2A}$$

$$k_3 = \frac{2F}{2W \cdot A} = k_1 = \frac{\lambda_3}{A}$$

$$k_4 = \frac{F}{(W/2)2A} = k_1 = \frac{\lambda_4}{2A}$$

The analogy to a parallel-resistance electric circuit is a multiple sliding-contact system and will not be treated in this paper.

It is proper at this point to consider the limitations of the hypothetical contact when applied to actual cases. It being assumed that the foregoing developments are logical, it is considered perfectly valid to let these concepts of wear resistance

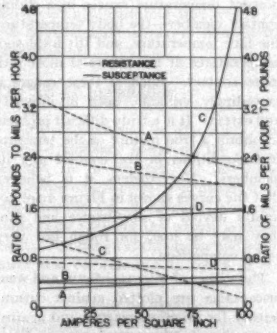

Figure 3. Wear resistance and wear susceptance versus current density for metal-graphite brushes—types *A*, *B*, *C*, and *D*

and wear resistivity absorb all of the variations in the physical properties of the contact member just as electrical resistance and electrical resistivity do for the case of electric conduction through any conductor. Thus, just as R under operating conditions is equal to

$$\frac{\rho l}{A} \times K(\text{temperature}) \times K(\text{stranding}) \times K(\text{skin effect}) \times K(\text{etc.})$$

so wear resistance may be set equal to

$$(\text{Wear resistivity})_a \times (\text{contact area}) \times K(\text{contact temperature}) \times K(\text{contact dimensions}) \times K(\text{contact pressure}) \times K(\text{sliding system}) \times K(\text{ambient conditions}) \times K(\text{etc.})$$

It should be pointed out that the adaptation coefficients for wear resistance as already given are not as simple as are those for the electric circuit. In the latter case these coefficients are both fairly simple and quite dependable. For wear phenomena, however, these coefficients are extremely variable and interdependent. A study of Figure 1 will verify this statement to a large extent.

The reciprocal of wear resistance, which may be called *wear susceptance*, has been found, in the case of electrical brushes, to be more easily understood than wear resistance. Since wear is the result of friction, it is more intelligible to think of the rate of wear per unit of friction than of the amount of friction per unit of wear rate. Likewise, the reciprocal of wear resistivity, which may be called *wear susceptibility*, is more useful than is wear resistivity.

Experimental

The curves shown in Figures 3 and 4 for four kinds of metal-graphite brushes were calculated from experimental data obtained at the Iowa Engineering Experiment Station and represent the average of repeated tests at each current density between 0 and 100 amperes per square inch at intervals of 20 each. The current used was 60-cycle alternating current. The measured data included frictional torque of the test brushes, their wear, and the spot temperature in a representative brush of each group tested. The wear is measured in mils and the wear rate in mils per hour.

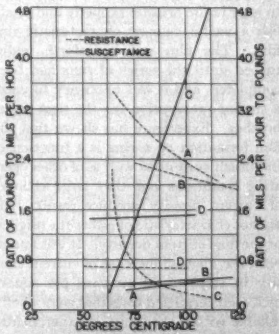

Figure 4. Wear resistance and wear susceptance versus spot temperature for metal-graphite brushes—types *A*, *B*, *C*, and *D*

The test equipment consisted of two units of similar construction, each having a slip ring of standard material driven by a separate motor. Each slip ring, together with its brushes, was enclosed so as to permit the control of atmospheric conditions. Eight brushes were placed radially on each ring with a normal pressure of three pounds per square inch of contact area and were tested at an average speed of 4,200 feet per minute.

The duration of each test run was the same, and data were recorded at regular intervals throughout each run. All values except brush-wear data used in the cal-

culations of the curves of Figures 3 and 4 represent the averages of these recorded data for a set of runs at each current density except for that obtained during the first hour of each run. This first hour's data were influenced by transient conditions that accompanied the start of every test run, but the rest of the data for each run were, for the most part, steady state. Both test units, which had previously been compared and checked for similarity of results on like brushes, were operated simultaneously in all runs. The brushes were tested as follows:

Types *A* and *B* simultaneously on units 1 and 2, respectively.

Types *C* and *D* simultaneously on units 1 and 2, respectively.

Each series of tests was preceded by a process of stoning and sanding followed by an operating period of sufficient length to wear in the brushes properly and establish a well-developed characteristic ring film. The film was henceforth undisturbed until the series of runs had been completed, and it was necessary to make a similar preparation for the next set of brushes. Experience has shown that the film formation on a ring is a function of the brush current as well as of other operating conditions and that large changes of current density produce results that are not characteristic of either the original or the final current density. It was found, however, that an increase of current density in steps of 20 amperes per square inch each permitted tests that were wholly reliable within the limits of experimental error. Several runs were conducted at each current density before proceeding to the next.

The frictional force, which is measured in pounds, was obtained by converting the electrical input to the driving motor into the torque required by the brushes. The efficiency data required for these conversions were revised for every test run, so as to prevent, insofar as possible, the errors due to the variable losses of the test equipment.

The brush-wear data were obtained by making four micrometer measurements, each to the nearest 0.0001 inch, on each of the eight brushes, before and after each run. The difference between successive readings for each of the 32 points helped to determine the average brush wear for that set of brushes.

The spot temperature was measured by a thermocouple junction placed in a hole drilled in the top of one brush in the group being tested. It has been found that consistent use of the same point in all tests gives approximately the same comparative results as a group of thermocouples placed at various accessible points on a brush. This temperature, which is plotted as abscissa in Figure 4, does not, however, represent the true temperature of the contact face. There are three important temperature ranges in a sliding contact member—the body temperature, the face temperature, and the local spot temperatures at the points of most intimate contact. Each of these ranges is exceedingly variable, both in intensity and extent. It is a truly difficult problem to obtain a true picture of the temperature conditions in the contact and its members. Nevertheless, it is believed that the curves shown in Figure 4 are not totally devoid of significance and that they may be used for rough but very useful comparison.

The values of wear resistance and wear susceptance are plotted against current density for practical reasons and against temperature for theoretical reasons. Practically, the similarity of the curves of wear susceptance and wear resistance in Figure 3 to those obtained for rate of brush wear and its reciprocal, brush life, respectively, indicates that friction alone was not responsible for the variations in wear rates. The phenomenon of wear is a function of both its cause, which is friction, and the binding strength of the material, which restrains it to a varying degree. The binding strength is, in turn, a function of the temperature of the brush material, weakening as the temperature increases. Since the brush temperature increases with an increase in current density, it is reasonable to expect the ratio of the wear to the friction to increase likewise.

Theoretically, the curves of Figure 4 indicate the relative strength or weakness of the binding materials of the respective brushes for similar ranges of temperature. It is easy to recognize the superiority of the binding materials in brushes *A* and *B* and the great inferiority of the binder in brush *C*. It should be noted again that this ratio of wear to friction is almost completely independent of the external system and is almost wholly a property of the brush itself.

Conclusions

The development of concepts of wearing quality based on the truism that the magnitude of a phenomenon is proportional to its cause and inversely proportional to that which resists it has been given, and two of these concepts are shown for the actual cases of four kinds of metal-graphite brushes. Since electrical resistance, resistance to motion, and wear resistance are based on the above truism, it is no surprise that electrical, mechanical, and wear phenomena should be analogous to some extent. The table shown below illustrates the extent of the analogy for all three phenomena insofar as can be determined at present.

It is believed that these concepts, together with the chart of variables affecting brush wear shown herein, provide a more solid foundation for the furtherance of the study of wear of electrical brushes. It is recognized that a subject so inherently complex as an electrical sliding contact cannot be made simple. It is possible, however, to analyze the total phenomenon into its component parts and, where these component parts are also exceedingly complex, to analyze them further into simpler components, repeating the process until components that can be determined readily are obtained. The first step in this process of analysis has been suggested in this paper by the separation of the characteristics of the contact specimen itself from those of the outside system.

Apart from abstract analysis, however, wear resistance, wear susceptance, wear resistivity, and wear susceptibility are believed to provide new and important tools for the comparison of brushes or other materials used in sliding contacts.

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Parallel Operation of Airplane Alternators

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Synopsis: The increase in airplane electrical loads has made necessary an increase in the distribution voltage to avoid excessive copper weight. Difficulties in the use of higher d-c voltages are mentioned, and past experience with a 400-cycle three-phase system is outlined. In the light of this experience and of new developments in progress, requirements are outlined for a larger 400-cycle system with multiple generating units operating in parallel.

ELECTRICAL loads on military airplanes have increased tremendously in the last three years because of the substitution of electric power for hydraulic power to drive auxiliaries, or the use of motor-driven instead of engine-driven hydraulic pumps, and because of the development of new flight and combat devices.

The Trend Toward Higher Voltage

First in use because of its simplicity, the d-c system progressed through the 6- and 12-volt stages until, in 1939, new airplanes were designed with a 24-volt system.[1] As the loads increased, the weight of wiring required for the lower-voltage systems became prohibitive. Now, in 1943, the economical limit of the 24-volt system has been exceeded, with new airplanes demanding 1,600- to 2,000-ampere peak loads. A further increase in voltage is therefore necessary. Because of the continued upward trend of the load-demand curve, and because of the increasing transmission distances in the larger airplanes, the next step will be above 100 volts.

Unfortunately a change to 115 volts direct current on high-altitude airplanes introduces at least one problem to which a completely satisfactory answer has not yet been found. This is the difficulty of arc rupturing in the switching equipment at present and contemplated flight-altitude maxima for combat airplanes. Fault currents may be higher than for a-c equipment of equivalent rating. On small motors at this voltage, commutation at high altitudes is another problem. Partly for these reasons, the United States Army Air Force has selected a 208/120-volt 400-cycle three-phase four-wire system for the large combat airplanes now under development.

The XB-19 Installation

Early experiments by the Air Corps with a-c auxiliary power on the *XB*-15 resulted in procurement of auxiliary-engine-driven 400-cycle three-phase power plants for the *XB*-19. Figure 1 is a schematic view showing the circuit arrangement. The design of the engine and alternator was co-ordinated to result in the

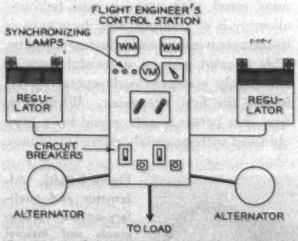

Figure 1. Schematic view of the auxiliary power plants used on the *XB*-19 airplane

package unit shown in Figure 2. The pancake proportions of the alternator do not give the optimum weight of electrical parts, but, in conjunction with the aluminum fan, provide the necessary flywheel effect for the engine. The use of 14 poles gives a synchronous speed of 3,430 rpm. The short-circuit ratio is 0.60, a figure which may seem low to a designer of 60-cycle machines, but which has proved satisfactory in operation. Heavy dampers with continuous end rings limit oscillation caused by engine-torque pulsation. They also help support the voltage until the regulator responds to a load increment. With a self-excited system, this materially assists in prompt recovery of voltage if the regulator is fast enough to take advantage of it.

The design rating of the alternator is 120 volts, 12.5 kva, 0.8 power factor, although, to conform to the Air Corps specification, the name-plate rating is 10 kva, 0.75 power factor. As the system is operated ungrounded, the neutral is not brought out.

The rotating field of the alternator is designed for overhung mounting on the engine crankshaft, which makes the use of a d-c exciter difficult. Chiefly for this reason, it was decided to use self-excitation. An electronic voltage regulator, using *RO*-585 diodes to control a three-phase half-wave thyratron rectifier, provides the fast-acting field supply so necessary in a self-excited system.

The *RO*-585 filaments are operated from a positive-phase-sequence network which delivers a single-phase voltage proportional to the average of the root-mean-square values of the three line voltages. As the regulating action is a function of the filament temperature in these tubes, the regulator is responsive to the average of the three root-mean-square phase voltages. An incidental advantage in using the positive-sequence network is the accomplishment of excellent temperature compensation by using in the resistance element of the network a material having a positive temperature coefficient of resistance.[2]

The flight engineer's panel, the installation of which is shown in Figure 3, contains the instrumentation and manual controls. The panel compartment houses the voltage build-up and reactive-load-equalizer circuits, the wattmeter current transformers, and the manual circuit breakers. Voltage is built up initially from an alternator residual voltage of approximately nine volts by means of a copper-oxide rectifier and a small multicontact Silverstat voltage regulator, both of which are intermittently rated to supply no-load excitation. A small high-reactance step-up transformer overcomes the initially high resistance of the rectifier without resulting in excessive excitation at normal voltage.[3] By this means the voltage overswing is reduced. For each alternator a three-position multicontact manual cam switch controls the starting sequence. This switch must be in the off position before the auxiliary-engine-starter circuit can be completed. With the engine at normal speed, the switch may be turned to the warm-up position, which allows the voltage to build up and be maintained under the control of the auxiliary regulator. After 45 seconds a thermal relay energizes a tripping magnet on the cam switch, automatically advancing the switch to the run position, although it may be returned to the off position at any time. The two cam switches are mutually interlocked to prevent an attempt to build up both alter-

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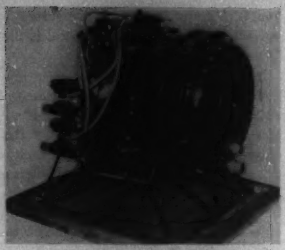


Figure 2. The 12.5-kva alternator assembled on the Ruckstell-Burkhardt auxiliary engine

nators at the same time, as only one build-up circuit is provided. As soon as one alternator is transferred to electronic regulation, it may be connected to the load bus by closing its manual circuit breaker, although, particularly at low ambient temperature, it is desirable to operate at no load for a few minutes to allow the thyratrons to reach normal operating temperature.

Operating Experience on the XB-19

With no load on the first alternator, and with the governors of the two engines closely matched, it has been found fairly easy to synchronize manually at full voltage on every attempt when the synchronizing lamps are flashing not faster than three cycles per second. At rates of slip up to six or eight cycles per second, it is possible to synchronize on approximately 75 per cent of the attempts with random closure of the breaker. With more than two or three kilowatts of load on one alternator, it is necessary to close while the lamps are dim or dark. Test experience with these power plants indicated the necessity of manual control of the engine governors, and this feature was added when the equipment was installed in the airplane. After some practice, and with the engines in smooth running condition, it was then possible for the operator to synchronize with full load on one alternator, although he would occasionally miss. When the engines have been run for a number of hours after an overhaul, momentary speed changes during attempts to synchronize make it difficult to do so with more than six kilowatts of load.

During the development stage, tests were made to determine if it were practical to synchronize by bringing the incoming alternator up to approximately synchronous speed with zero or weak field and allowing it to pull into step by means of its damper winding and reluctance torque. This attempt was not successful, because the highly reactive load severely overloaded the first alternator. While it is true that better results would have been obtained with separately excited machines, the shock would still be prohibitive when attempting to synchronize under load.

When paralleled units are driven by auxiliary engines, it is necessary to cut off promptly an alternator whose engine has failed to carry load. Magneto trouble, fouled plugs, and vapor lock, or other fuel-system faults, will occasionally cause a short-time or sustained power failure. Any tripping means for isolating such a unit should have its action delayed sufficiently to prevent operation on a momentary misfire which can be sustained by the inertia of the machine. On this equipment, protection is afforded by a reverse-power contact on the wattmeter which actuates a shunt trip magnet on the circuit breaker. This contact is set at three kilowatts, and the damping of the instrument gives the necessary delay. A small pilot relay inside the instrument case relieves the pointer contact of the tripping current.

Experience with the system has demonstrated the desirability of a uniform response rate of the several governors. If the rates differ materially, one engine tries to drive the other on the sudden removal of a large load, and faulty tripping of the reverse-power device may result. A particularly bad performer is a governor which has sluggish response in correcting overspeed. Although the condition was reproduced during preliminary testing, no serious trouble has been experienced in service operation.

Experience with the scheme for automatically building up the alternator from its residual voltage has been generally good but subject to occasional failure caused by a reduction of normal residual flux. This usually follows a shutdown caused by loss of voltage resulting from a highly inductive overload, and may occur after an engine failure has transferred all

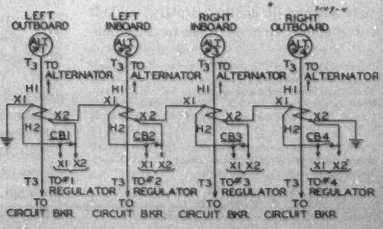
Figure 3 (left). Alternator and auxiliary-engine instruments and manual controls at the flight engineer's position of the XB-19 airplane

The two plunger knobs in the lower right-hand corner of the picture permit manual control of engine speed while synchronizing

Photo courtesy of Douglas Aircraft Company

Figure 4 (below). Standardized current-transformer interconnections for feeding the reactive load-equalizer networks of the voltage regulators

Agreement on polarities is necessary to permit interchanging regulators of different manufacture



of the load to the remaining alternator. It may also be discovered after the flight engineer has mistakenly shut down an engine without first opening the alternator circuit breaker. To overcome this condition, a circuit has been added which permits the operator to "flash" the field with battery voltage if necessary.

Requirements for a Modern A-C Installation

Having examined an existing a-c installation, we may proceed to lay down the requirements of an airplane power system which will take advantage of the experience gained and the newer developments which are available. It cannot well be denied that a successful system must involve parallel operation of a number of generating units. It is not acceptable that the loss of a single unit can shut down the whole system. The loss of one unit out of two is nearly as bad, unless the essential load is within the rating of one generating unit. This condition might exist in a noncombat airplane, but the greater hazards of combat operation dictate the use of at least three and preferably four units where the size of the airplane permits. Nonparalleled or isolated operation of the several generating units is a makeshift which does not use to the full the power capabilities of the system in starting heavy motor loads and self-clearing of faults; that is, the load factor with separate units is poor. Loss of a generating unit results in a delay before the load can be reapportioned among the other units.

The ability to parallel alternators depends first on the characteristics of the prime movers. The earlier a-c aircraft systems used auxiliary gasoline engines governed to run at essentially constant speed. The governors are designed to droop the speed slightly as load increases, which characteristic automatically gives acceptable division of kilowatt load between units. As the capacity of the prime mover is comparable to that of the alternator, and the inertia is relatively low, no difficulty has been experienced in maintaining synchronism under all conditions, including load transients. In the *XB*-19 equipment, the use of low-resistance damper windings effectively prevents hunting caused by engine-torque pulsations. Whereas the use of auxiliary engine drive may be satisfactory for medium-altitude transport and cargo airplanes, at the present time it seems to be impractical to supercharge the smaller engines to a critical altitude sufficiently high to permit their use on high-altitude bombers.

Constant-Speed Drives

Until recently, no suitable means was available for driving alternators from the main engines and at the same time permitting parallel operation. Now several so-called "constant-speed" drives are under intensive development and promise to have the necessary performance. The input–output speed ratio is continuously variable, so that a constant output speed may be maintained over a wide range of input speed. This development gives the a-c electric-system prime movers of proved reliability and high-altitude performance.

A number of difficulties must be overcome in adapting constant-speed drives to this application. Because of the large size of the main engine in proportion to the rating of the alternator, the engine is a rock-steady source whose speed is practically unaffected by alternator loading. On the other hand the engine speed may suddenly be changed because of flight requirements; yet the alternator should not perceive this change. As a result, the drive or its governor must incorporate the load-dividing feature, and the governor must be quick in coming into action and be able to change the drive ratio at a rate faster than the engine can accelerate. In a speed-converting mechanism the difference between the input and output torques appears as a torque reaction on the housing, and it appears to be unavoidable that this reaction torque is transmitted principally through the ratio-changing mechanism. Consequently at high ratios the ratio-changing device must develop considerable power to alter the ratio.

The necessary rate of change of ratio is determined by the maximum possible rate of acceleration or deceleration of the engine. Information from one of the engine manufacturers states that an acceleration rate of 3,000 rpm per second may be found in normal operation, although it is considered detrimental to engine life, and that a rate of 3,500 rpm per second is possible under some combat conditions with hand control of the propeller pitch. The drive should be capable of responding at a rate somewhat faster than this to have a reasonable factor of safety. It seems probable that the engine deceleration rate will be appreciably less than 3,000 rpm per second, although no confirming data are known to the author.

Because of the rigidity of the prime movers, it is essential that the drives incorporate overrunning clutches to permit the alternators to remain in synchronism in spite of momentary deviations in drive ratios or failure of the drives to compensate promptly for rapid changes in engine speed. Partly for the same reason, it is desirable that the drive have some internal slip, either inherent or introduced by the use of a slip coupling such as a fluid flywheel.

Unless the drive has an inherent slip which is consistently reproducible and is independent of the ratio setting, it is necessary that the governor be made load-responsive to provide the speed droop which is required for division of kilowatt load between paralleled alternators. Methods are known for obtaining load division by controlling the relative phase position of the alternator rotors without producing a change in the steady-state speed, but they lack the simplicity and reliability of the speed-droop method. Though the governor may be the droop-determining means, it will have some delay in adjusting itself to a new load level. For this reason some inherent slip in the drive will assist in the maintenance of synchronism during sudden large load transients. Internal slip will also reduce the effect of engine and drive torque pulsations.

While the governor must have a rapid response rate, it must also be well damped to obtain system stability during load and fault transients. Keeping the force-inertia quotient of the ratio-changing device high will make the damping problem easier.

Alternator Design

Experience with the self-excited a-c system has demonstrated a degree of overload capacity and system stability inferior to that which may be expected with separate excitation. The load characteristic of the self-excited machine has a definite knee beyond which the voltage is not self-supporting, with the result that a suddenly applied heavy load may cause loss of voltage, whereas the same load gradually applied may be sustained. Synchronizing difficulty is increased, and the ability to burn minor faults clear or blow limiters is distinctly reduced. Alternators of current design have integral d-c exciters to overcome these handicaps.

Low-resistance damper windings are necessary to ensure freedom from oscillation excited by driving torque pulsation or load transients. Some assistance is given in synchronizing by the full-voltage method because of the damping effect on oscillations caused by closing the circuit breaker at inexact synchronous speed and phase position. When synchronizing is performed by the synchronous motor

method, that is, bringing the incoming machine up to approximate speed with no field or with weak field and closing the breaker, low-resistance damper windings are essential, and some benefit is obtained by using continuous end rings. The latter feature will also increase the ability of the alternator to pull back into step automatically under some conditions of out-of-step operation.

It has been suggested that aircraft alternators should be designed with a short-circuit ratio around unity because 60-cycle practice has shown that this gives high inherent stability which will be a benefit in parallel operation and in starting heavy motor loads. The suggestion has merit, but unfortunately it results in a heavy machine. Much of the benefit may be obtained with lighter overall weight by increasing the capacity of the exciter to supply heavy excitation when needed and by making the regulator as fast as possible. Satisfactory experience with self-excited alternators having a short-circuit ratio of 0.60 discounts the necessity of accepting the higher weight of the design which has a higher ratio.

The Voltage Regulator

The use of an exciter brings the regulator duty within the capacity of existing designs of aircraft d-c regulators which have undergone extensive development and combat service during the past two years. What modifications are necessary can readily be made to adapt them to the requirements of the a-c system. If the operating coil is supplied from a three-phase dry-plate rectifier, the regulator will respond to the average of the three average phase voltages. The fact that this is an average rather than a root-mean-square response is not expected to be objectionable with alternators whose harmonic voltage output is within the limits set by the Army Air Forces tentative specifications. The tentative specification for the voltage regulators recognizes the necessity for this average response by stating that the voltage will be checked on type test with a rectifier-type voltmeter calibrated to read root-mean-square values of sine-wave voltages.

The regulator includes a network designed for use in a series-type differential reactive load-equalizer circuit for causing the regulators to equalize the circulating reactive current between alternators operated in parallel. The network is connected to a 125/1-ratio current transformer in the T3 lead from the alternator. Zero-power-factor lagging current from the transformer develops across the network a voltage which is in phase and in series with the line voltage applied to the regulator-coil-circuit rectifier. Since this increases the voltage applied to the regulator coil, the regulator acts to decrease the alternator excitation. Conversely, the presence of zero-power-factor leading current will cause the regulator to increase the excitation. Inphase line current produces a network voltage at a right angle to the voltage applied to the regulator and therefore does not affect the operation. Figure 4 illustrates the differential equalizer circuit which has been selected as standard by the interested manufacturers to ensure interchangeability, and this has been incorporated in the tentative specification by the Army Air Forces. With this connection, if the line currents of the respective alternators are equal in magnitude and phase angle, the transformer secondary current circulates solely through the secondary circuits and produces no voltage drop across any of the regulator networks. If one machine delivers more than its share of current, the secondary difference current divides proportionately in the parallel impedance paths formed by the regulator network of the overloaded machine as one branch and the other regulator networks in series as the other branch. With an excess of lagging current delivered by the first alternator, the phase angle of the network voltages in the two branches is such that the excitation of the overloaded machine is reduced and that of the others is increased, with the result that the reactive load balance is restored without affecting the voltage of the system. This lack of effect on the system voltage while correcting a reactive-load unbalance is the advantage which the differential method holds over the somewhat simpler scheme in which balance is achieved by drooping the voltage of each alternator in proportion to the lagging reactive component of current which the machine is delivering, thus producing a droop in system voltage. The differential scheme is identical in principle with the load-equalizing method which is used in present aircraft d-c systems. An improvement over the d-c circuit is the use of a normally closed interlock on the alternator circuit breaker to short-circuit the secondary winding of its associated current transformer when the breaker is open, and so avoid a reaction of the idle alternator circuit upon the regulated voltage of the other loaded machines. To be effective always, this interlock should be designed with the knowledge that it must effectively short-circuit a low voltage. Proper choice of contact materials and contact pressure and the use of several contact points in parallel will avoid trouble caused by contact film and dirt.

Special antihunting or damping means are necessary in the a-c voltage regulator because of the additional field circuit delay which is introduced by the use of an exciter. A very effective method uses a transformer to introduce into the d-c circuit of the regulator coil a voltage proportional to the rate of change of exciter voltage or the rate of change of alternator field current. When introduced with the proper polarity, this voltage causes the regulator coil to anticipate the response of the line voltage, which effect tends to damp out a tendency to hunt or overshoot.[4]

Choosing a Synchronizing Method

The choice of a synchronizing method is somewhat dependent on the prime movers which are used. If the system is driven solely by constant-speed auxiliary engines, a manual or semiautomatic method may be acceptable, because synchronizing is performed infrequently and at a time when the flight engineer is less occupied with other duties. It may be permissible to drop all or part of the load before synchronizing. With main-engine drive, on the other hand, fully automatic synchronizing is definitely desirable, because the availability of electric power is dependent on engine speed conditions, which in turn are determined primarily by warm-up, ground-maneuvering, and flight requirements. When the several alternators come up to speed, the flight engineer may have other duties requiring his attention. With automatic synchronizing, each alternator becomes available for loading as soon as it reaches synchronous speed.

Automatic Synchronizing

Automatic synchronizing equipment has been used in unattended substations and small power stations for many years with excellent service records. For aircraft use the same principles can be applied, but many refinements may be eliminated because of the presence of supervision and the necessity of saving weight. The essential features may be stripped down to means for performing the following functions:

1. Determine when the alternator frequency has approached normal, and initiate the succeeding sequence.

2. Indicate whether the bus is dead or already energized. If it is dead, initiate circuit-breaker closure; or if it is alive,

initiate the synchronizing sequence as follows:

3. Act on the incoming governor to adjust the speed until the difference frequency approaches zero.

4. Close the circuit breaker when the difference frequency is less than about two cycles per second and the alternator and bus voltages are closely in phase.

5. Advance the governor to the normal load setting.

6. Open the circuit breaker at any time when the system frequency drops below the acceptable minimum.

Automatic synchronizing by this full-voltage method may be accomplished with a load on the system, because the human elements of indecision and reaction time are eliminated from the operation. Nevertheless manual controls are provided so that the flight engineer may select the units to be paralleled, or he may trip any alternator circuit breaker at any time. After a machine has been connected to the bus, the flight engineer may, at his leisure, correct any inequality in load division or error in frequency by a manual control which acts through the speed-matching device to adjust the governor setting. Thus he has full control over the operation of the system but is relieved of the necessity of performing the somewhat critical operation of simultaneously matching speed and phase position and closing the breaker at the correct instant. With four alternators he would otherwise have to go through this cycle three times in succession shortly before the time of take-off.

Manual Synchronizing

The weight of the control equipment can be reduced by using manual instead of automatic synchronizing methods, but the saving in weight must be balanced against the increased burden on the flight engineer, the increased chance of an outage caused by faulty manual technique, and the decreased availability of the generating equipment because of failure to connect it to the bus promptly. Perhaps the least objectionable in these respects is a semiautomatic system which differs from the one previously described in that the automatic speed-matching feature is replaced by a manual control. This arrangement requires the attention of the flight engineer at each synchronizing operation but greatly eliminates the factor of faulty manual technique, because the automatic means for determining when the breaker should be closed are retained. The weight saving in comparison with the fully automatic system is approximately two pounds per alternator.

Of the straight manual synchronizing schemes which have been proposed for airplane use, perhaps the most foolproof is the one in which the alternator is synchronized in a manner which is common for synchronous motors. The incoming machine is brought up to slightly below synchronous speed with zero or weak field, the circuit breaker is closed, and the machine accelerates toward synchronous speed because of the motoring effect produced by its damper winding. When it is close enough to synchronous speed, it will be pulled into step by its reluctance torque. If this is done with no field excitation, there is a 50–50 chance that it will pull into step with the wrong pole position and will have to slip a pole pitch when field is applied. If the breaker is closed with weak field on the machine, the pulsating current will be higher, but the machine will pull in with the correct pole position. An advantage in starting with weak field lies in the fact that synchronizing lamps may be used as an indication of slip speed while the speed is being raised by manual adjustment of the governor before the breaker is closed.

An important disadvantage of this synchronizing method is the high motoring current which is drawn even at a low slip. Calculations on the present design of airplane alternator indicate that this will equal rated full-load current at about one per cent slip and 160 per cent of full-load current at about five per cent slip. Furthermore, this current pulsates badly at slip frequency. The current calculations were made with the assumption of an infinite bus, and the actual current will be somewhat less. This will increase the time of the system disturbance. The nature of this effect is substantiated by tests which were made during the development of the equipment for the *XB-19* airplane. With one machine on the bus, synchronizing the second machine by this method will be difficult with a load of more than 50 per cent of the alternator rating. It may be found necessary in practice to remove the system load before synchronizing the second alternator.

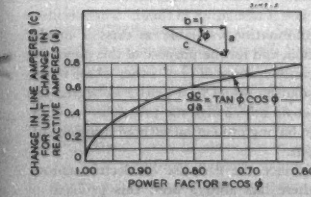


Figure 5. Rate of change of ammeter reading with respect to the reactive component of current plotted against power factor

At normal power factors the ammeter is an insensitive indicator of correct voltage-regulator equalization

Adjusting the Voltage Regulators

Experience has demonstrated the difficulty of convincing airplane crews that kilowatt load in an a-c system cannot be balanced between paralleled alternators by adjustment of the voltage regulators. Having had instruction and more or less extensive experience with d-c systems, they must be shown by example that the two systems are not alike in this respect. As serious misadjustment may be encountered, and as this will have an adverse effect on stability because of unequal field excitation, the process of regulator adjustment must be made as simple as possible.

The fact that ammeters are not good instruments to follow when adjusting the regulators is emphasized by Figure 5, which shows how the ammeter reading varies with the changing reactive current, the inphase current remaining constant. At 0.75 power factor the ammeter responds two thirds as fast as the reactive component, whereas at 0.87 power factor the response is only one half as fast as the change in the reactive component. The matter is further complicated at small loads by the fact that a-c ammeter scales are condensed in this region. At normal power factors the inphase component of current has a greater effect on the ammeter reading than the reactive component does, so that a change in power factor or a change in load balance caused by governor aberrations while the regulators are being adjusted will be extremely confusing.

Figure 6. Mock-up model of 40-kva alternator of current design

Because regulator adjustment directly affects the reactive current balance between paralleled machines, varmeters (which read "volt-amperes reactive") give a positive indication of the condition of

Principles of Aircraft Electric-Motor Protection

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Introduction

IN writing a paper of this kind for the AIEE, it is needless to say that one part of the aircraft electric-motor protection problem is protection from excessive temperatures. The major problem with the aircraft electric motor is to make available its maximum output before the protector disconnects the aircraft electric motor from the line.

The problem involved in applying an aircraft motor protector for maximum output under all conditions may be realized when it is considered that today an aircraft may be stationed on a field in the tropics and within 24 hours it may be moved to a field well within the Arctic Circle. Or, even more striking, an aircraft may be stationed on a field in the tropics with the sun beating down so as to cause temperatures as high as 70 degrees centigrade in compartments where electric motors are located. In a few minutes this aircraft may be flying at a high altitude where the ambient temperatures may be as low as −60 degrees centigrade.

In domestic, commercial, and industrial uses of electric motors, it has been the aim to protect electric motors so they would not be personal or fire hazards. In accomplishing this, it has been good engineering practice to provide an ample margin of safety. In October, 1942, C. P. Potter presented a paper before the AIEE entitled "The Inherent Overheating Protection of Single-Phase Motors" from which I quote his comments regarding the summary of the data for the tests under various loads, voltages, speeds, ambients, and amounts of ventilation:

"CONCLUSIONS

The variations in temperature shown in the table are small and lead to the conclusion that inherent overheating protective devices mounted inside fractional horsepower single-phase motors completely protect them against all abnormal operating conditions."

There are many engineers who believe that all motor protectors will limit the work output of electric motors, and they advocate that the operator should have the privilege of destroying the aircraft electric motor if by so doing he thinks he can accomplish his mission. It is questionable if any operator has the ability to judge properly during the stress of emergency as to when he should or should not destroy a motor.

A good automatic device will always repeat its performance, and in this paper it will be assumed that a properly designed and properly applied electric-motor protector must not place any limitations on the potential work output of the electric motor.

Stated in the simplest terms, the problem is to establish principles to follow in protecting aircraft electric motors from destructive temperatures without limiting output regardless of the loads or the ambient encountered.

While there are many classes of insulation in use in aircraft electric motors, many of these electric motors have some class *A* insulation in them. There is more information available on class *A* insulation, and for the purpose of this paper the consideration of any other class of insulation would be a matter of degree and would not change the principles to follow in having protection without limiting output.

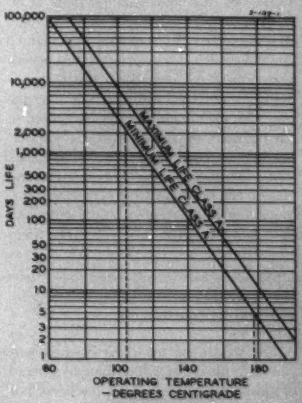

Figure 1. Effect of temperature on life of insulation

Since the first use of electric motors, there has always been this problem of temperature protection. First, fuses were used, then current-sensitive devices mounted remote from the electric motor, and since 1929 there has been an increasing use of built-in electric motor protectors. E. J. Schaefer, formerly of the regulator equalization. Not being responsive to real or kilowatt load, they will not give confusing readings because of governor misadjustment. A varmeter is nothing but a wattmeter with a reactive compensator to shift the potential coil voltage 90 degrees from its true position. Since wattmeters are already necessary in the system to permit supervision of loading and adjustment of the governors, the addition of reactive compensators and a simple switching arrangement make them useful for regulator adjustment also.

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Conclusions

A background of experience exists to guide the development of 400-cycle power systems for airplanes, and this knowledge is being used to advantage in the present program of expanding the installed capacity. To duplicate the reliability of the present d-c system, parallel operation of the alternators is required. Parallel operation of auxiliary-engine-driven units already has been accomplished, and, given constant-speed mechanical drives with the correct characteristics, this performance can be duplicated with main-engine-driven alternators. The numerous duties of a flight engineer on a multiengine airplane make it highly desirable to provide automatic synchronizing control to increase the availability of the power system and eliminate outages caused by man failure during the synchronizing operation. Equipment for doing this is available or is being developed.

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fractional motor engineering department of the General Electric Company, in a paper entitled "Protection of Automatically Started Fractional Horsepower Motors," published in the September 1940 issue of the *News-Bulletin*, of the International Association of Electrical Inspectors, shows that only with a properly built-in protector can there be protection and at the same time approach maximum motor output under any possible load condition.

Many aircraft electric motors have intermittent-duty cycles and in order to conserve weight the motors are operated at high speeds, and these intermittent-duty motors are regularly operated at high overloads as compared to a continuous running rating. This results in motors of small size which presents a space limitation for the location of the protector.

Location of Protector

It takes no data or lengthy discussion to convince one that theoretically the proper location for the protector would be at the danger hot spot where it would be responsive to the danger hot-spot temperature. Because of physical limitations, this is impossible; so, there must be a compromise by preparing a location when designing the motor body that will give the thermostatic element the best possible opportunity of absorbing heat from the danger hot spot.

Temperature at Which to Protect

Regardless of the kind of insulation used, insulation life is dependent on both time and temperature. This is best illustrated by the life-temperature curve for class *A* insulation, Figure 1 of this paper, copied from page 434 of the book "Insulation of Electrical Apparatus," by Douglas Miner.

Class *A* insulation is listed by AIEE as good for a maximum safe operating temperature of 105 degrees centigrade. From the curve, it can be seen that this will give a minimum expected life of 2,000 days. The tentative Army-Navy (AN-M-10) electric motor specifications require that the protectors provide a minimum life of five continuous hours of operation under locked rotor conditions without damage to the motor. To provide sufficient manufacturing tolerance, it would be desirable to select a temperature corresponding to a minimum life of five days. This gives a temperature of 178 degrees centigrade.

Even with the selection of this high maximum allowable operating temperature for five days' life of the insulation, it should be remembered that in normal applications the actual operating temperature of the motor will be far below this value. This is best illustrated by Figure 2.

Line *A* represents room ambient of 25 degrees centigrade.

Line *B* represents the maximum winding operating temperature of 105 degrees centigrade under normal loads and 25 degrees centigrade ambient temperatures.

Line *D* represents the maximum winding temperature at which there is a tendency for most engineers to protect the motor. If this temperature of 120 degrees centigrade were selected, it is obvious that a small overload or an abnormally high ambient would cause nuisance tripping of the protector as there is very little winding temperature difference between full load and the point where the protector would open.

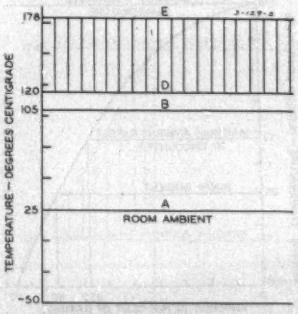


Figure 2. Chart of temperature levels involved in aircraft electric-motor protection

Line *E* is the 178 degree centigrade temperature selected for a minimum of five days' life from Figure 1.

To get protection without limiting the work output of the motor, the protector must control the motor winding temperature at 178 degrees centigrade, line *E*. The shaded area between the curves *D* and *E* represents the thermal capacity which most motor designers would not use. Thus, if protection were applied on the basis of line *D*, representing maximum winding temperature, it would lead to the condition where the aircraft designers (and others) would know that there was additional capacity available in the motors as indicated by the shaded area, and he (or they) would then rather have the operator run the risk of burning out the motor than be limited in power output as indicated by line *D*. The values used in this paper are on the basis that the winding temperature is the limiting hot spot; other hot spots would have different hot-spot maximum temperatures.

The Danger Hot-Spot Temperature

The temperature that will first cause damage to an aircraft electric motor need not be the winding temperature as indicated heretofore, or even the highest temperature in the motor. The first damage may be at the brushes, the solder, or the shunt leads to the brush-holder, and so forth. It is necessary to determine where the danger hot spot is and how hot it gets. This may be estimated at the time of designing, but the actual data can be obtained only by test with thermocouples and other temperature-measuring devices located at every point of possible damage.

Figure 3 is a photograph of such a test setup with eight thermocouples and four voltage-drop leads mounted in the motor. To be complete, these data should be obtained not only at room ambient but also at the maximum and minimum ambients at which the motor is expected to operate, and with various loads from the maximum continuous load the motor can carry without exceeding the maximum allowable hot-spot temperature through and including locked rotor. This is necessary because, for example, under locked rotor the armature windings may be the danger spot, and during running the danger spot may be shifted to the solder on the commutator.

Thermal-Element Operating Temperature

We know that the heat dissipation, or in other words the capacity of a motor, will vary with ambient. The accurate calculation of the capacity at different ambients would involve the use of a number of empirical values based on test data which are not available today. As the major portion of the heat is generated in the copper windings, a simple method of indicating the trend would be to use the following formula:

$$R_x = R_n \sqrt{\frac{T_m - T_x}{T_m - T_n}}$$

R_x is the current rating at a given ambient.
R_n is the current rating at room temperature (25 degrees centigrade).
T_m is the maximum allowable temperature (178 degrees centigrade).
T_n is the room temperature (25 degrees centigrade).
T_x is the given ambient temperature.

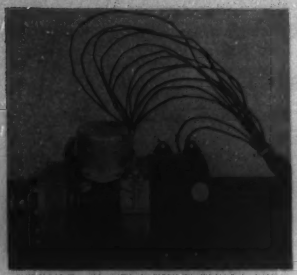


Figure 3. Aircraft electric motor equipped with thermocouples and resistance leads

The maximum allowable winding temperature previously adopted in this paper was 178 degrees centigrade. It is assumed that an intermittent-duty motor when carrying 80 per cent of its rating continuously at normal room ambient (25 degrees centigrade) will have a temperature rise of 153 degrees centigrade, resulting in an operating temperature of 178 degrees centigrade.

The curve in Figure 4 is obtained by using these values in the formula. It has been assumed that this intermittent-duty motor when running continuously would only carry 80 per cent of its rating at 25 degrees centigrade ambient. It would carry more load at lower ambients as indicated by the curve at −50 degrees centigrade, where it will carry 97 per cent of its rating continuously. At high ambients the motor output would be limited below the 80 per cent. At 70 degrees centigrade ambient the curve shows the motor will operate continuously at 67.5 per cent of rating. At an ambient of 178 degrees centigrade, the motor should not operate at all because the hot spot is already up to the maximum allowable temperature.

The information in this curve may be stated as follows: At any ambient there is one value of continuous load current that will bring the danger hot-spot temperature up to the maximum allowable value of 178 degrees centigrade (line *E*). If the protector is going to allow the motor to attain this temperature (178 degrees centigrade) at all ambients before removing the motor from the line, a protector will be needed that will have the same ambient characteristics as the motor it is to protect. As the operating temperature of the thermal element must be a fixed value, and if it is to match curve Figure 4, the thermal element must operate at 178 degrees centigrade when carrying zero load. This then establishes the operating temperature of the thermal element at 178 degrees centigrade. It can be stated that theoretically for continuous running loads the operating temperature of the thermal element of the protector should be the same temperature as the temperature of the hot spot to be protected.

Function of the Heat Generated in the Protector

When discussing the location of the protector, it was stated that it was physically impossible to locate the protector at the hot spot. With the protector located in a compromise position, it cannot be expected that the protector will be heated by the temperature of the danger hot spot up to the hot-spot temperature. This is illustrated graphically in Figure 5.

Curve *M*, the ambient temperature

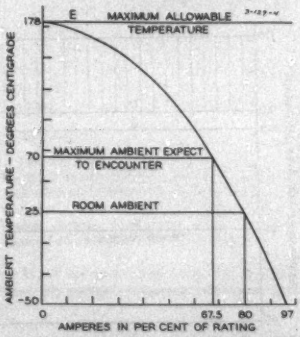


Figure 4. Ambient versus per cent load curve

versus motor continuous carrying capacity, is the calculated curve from Figure 4, and with a protector mounted in this motor, the curve of the protector temperature, that is, the temperature of the metal parts of the motor which surround the protector, would fall between curve *M* and curve *E*. The exact location of curve *P* would depend on how sensitive the protector was to the hot-spot temperature it is to protect. As the protector is a part of the motor assembly, the shape of the protector temperature curve *P* will be similar to curve *M*. But, regardless of where the protector is mounted, the protector location temperature under continuous operation would be greater than the ambient temperature curve *M* and less than the operating temperature of the thermal element curve *E*.

In order to use a thermal element operating temperature of 178 degrees centigrade, some method must be used to raise the thermal element temperature from that temperature surrounding the protector, curve *P*, up to 178 degrees centigrade. This can be accomplished by generating heat in the protector. Figure 6 is a schematic diagram of a protector with a heater built in for this purpose. This heater is connected so that the load current passes through it and the thermal element, and the heat generated in the protector is proportional to the current flowing at various loads, thus furnishing a variable temperature rise to the thermal element depending on the load current. Therefore, at any ambient there is a per cent of motor load current that will not only cause the hot-spot temperature to reach 178 degrees centigrade, but that same value of current can be used to cause the thermal element to reach the same temperature.

To illustrate, take the point at 70 degrees centigrade ambient. From curve 4, 67.5 per cent rated current will raise the danger hot-spot temperature to 178 degrees centigrade and from curve Figure 5 at this same 70 degrees centigrade ambient, the motor heats the protector to 125 degrees centigrade and the heat generated in the protector must raise the thermal element up to 178 degrees centigrade. Therefore, it can be seen that the horizontal crosshatched area indicates the temperature rise imparted to the protector by the heat of the motor and the vertical crosshatch indicates the temperature rise that must be imparted to the thermal element by the heater.

Ultimate Trip

So far, continuous performance of the motor has been discussed, and, if, after running sufficiently long to reach maximum stable conditions for any given

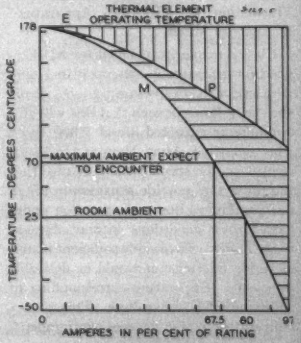


Figure 5. Motor ambient and protector temperature curves

ambient, there would be some change in these stable conditions, such as a rise in the ambient temperature or a slight increase in load current, both the hot-spot and the thermal-element temperature would rise, but as the protector would operate at any temperature in excess of 178 degrees centigrade, the motor would have reached an *ultimate* running condition as the protector would remove the motor from the line. This is called *ultimate trip* and may be stated as that value of load current which at a given ambient will cause tripping of the protector when the motor has reached a stable condition.

Locked Rotor

Locked rotor is the most severe load condition that can be imposed on the motor. Therefore, it is necessary that the protector take care of this condition in a satisfactory manner. For continuous running, the temperature of the protector would not follow the hot-spot temperature. So, under locked rotor, the protector temperature will lag still further behind the hot-spot temperature. This is illustrated in Figure 7.

F is the time-temperature curve of the danger hot spot for locked rotor. Since the locked-rotor current is high, the temperature will rise so rapidly that the protector (curve *G*) absorbs very little temperature from the motor before the hot spot has reached a dangerous temperature. This means that when the rotor is locked, the heat generated in the protector must furnish all of the temperature rise to the thermal element to bring it up to 178 degrees centigrade. The shaded area of Figure 7 shows this temperature rise that must be furnished by heat generated in the protector for 25 degrees centigrade ambient.

Some engineers think that locked-rotor protection is all that is needed for d-c aircraft electric motors. This thinking is based on the fact that the duty cycle of most aircraft electric motors is very short, and the major troubles come from

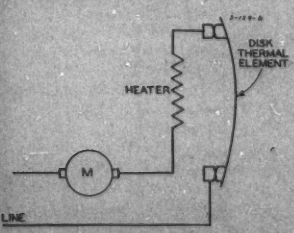


Figure 6. Schematic diagram of heater-type motor protector

jammed mechanisms which cause stalling of the rotor. Then, as soon as the rotor stops, it heats rapidly as shown in curve *F* of Figure 7. With a constant voltage supply, the current falls off because of the increased resistance of the windings, and the motor starts losing torque.

If protecting the motor from destructive temperatures was all there was to consider, a protector that provided locked-rotor protection would be a satisfactory protector, and holding the motor on the line for only one second would be sufficient time to let the motor start if free to do so. In aircraft there are many times when mechanisms are not jammed but are damaged sufficiently to introduce loads approaching blocked conditions, and at the same time the motor is able to turn over slowly. While it may take a relatively long time for it to complete its work, the chances are that the motor will do some good if it can be kept operating without burning out. This means that

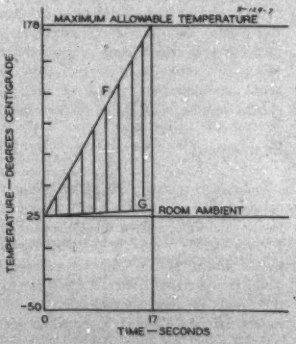


Figure 7. Heating curve for locked rotor

for locked-rotor conditions, the motor should not be taken off the line until the danger hot spot has reached its maximum allowable temperature. In providing locked-rotor protection without regard to the maximum output, it is possible either to overprotect, so as to cause nuisance trip-outs, or to underprotect so that the motor will burn out at normal loads or running overloads.

Overprotection is illustrated in Figure 8. Here the motor is carrying an excessive load but has not reached a stalled-rotor condition before the danger hot spot reached the maximum allowable temperature. The curve *J* is the time-temperature curve under a high running overload, and *K* is the time-temperature curve of the protector location. If this protector were one that took the motor

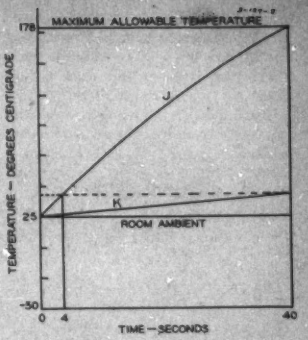


Figure 8. Heating curve at high overloads

with locked rotor off the line in one second, then under this extreme running condition the protector would have taken the motor off the line in probably four seconds, and the motor output would be limited to a small amount of work, and the danger hot spot would have been only 35 degrees centigrade. This kind of locked-rotor protection would not provide the maximum possible output of the motor. By proper design of the protector as to the heat generated in the thermal element, the operating temperature of the heater, the amount of heat, and its location with respect to the thermal element, it is possible to have some control over the rate of temperature rise of the thermal element so that regardless of the load conditions the protector will let the danger hot spot approach its maximum allowable temperature before disconnecting the motor from the line. Under these conditions, the motor can give maximum work output with protection from destructive temperatures regardless of load current or ambient.

Loads Less Than Maximum Continuous Running

Any load below the continuous value that will not heat the danger hot-spot temperature up to its maximum allowable temperature has not been considered in this paper, for, obviously, no protection would be needed for this condition.

Intermittent Loads

Up to this point, the two extremes of load that would call for protector operation to protect the winding hot spot have been discussed:

1. The maximum continuous running load.
2. Locked rotor.

Any value of intermittent load that would call for protector operation in protecting the winding hot spot would fall between these two extremes and need not be given any special consideration.

Regardless of the ambient conditions or load above maximum continuous running, it would be expected that a motor with an inherent overheat protector designed and applied according to the principles laid down in this paper would give a constant maximum danger hot-spot temperature as illustrated in Figure 9.

Curve *N* is the temperature of the danger hot spot for any value of overload or locked rotor and shows the same hot-spot temperature for all ambients.

In following out these principles, protector and motor designers are confronted with limitations, such as

1. Applying protectors to existing motors.
2. Limitations as to materials for the insulation of the protector.
3. Space limitations.
4. Physical properties of materials for the thermal elements and for the heaters.
5. Manufacturing tolerance more particularly of the motor than the protector.

In view of these limitations, some deviation would be expected from the theoretical curve *N* in Figure 9.

The curves in Figure 10 (results of tests on a protected aircraft electric motor) show how surprisingly close a protected motor can come to the theoretical conditions when a protector is designed and applied in line with the principles of this paper.

Conclusions

In conclusion, these principles can be summarized as follows:

1. Prepare a protector location when designing the motor.
2. Select those points in the motor will h are likely to be the danger spots and assign to each such point the maximum temperature possible.
3. Locate the danger hot spot by test with thermocouples and resistance rise measurements.
4. Adopt a thermal-element temperature as close as possible to the protection temperature of the hot spot to be protected.
5. Do not overprotect under any load condition; let tolerance be on the side of a possible loss of a motor now and then rather than rob all motors of a given design of any potential capacity.
6. Supply the difference in temperature between protector location and the thermal-element operating temperature by a heater built into the protector.

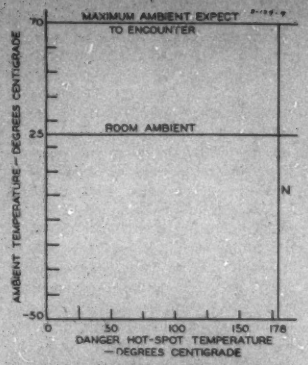


Figure 9. (Theoretical inherent protected motor) ambient versus hot-spot temperature for maximum safe load or overload

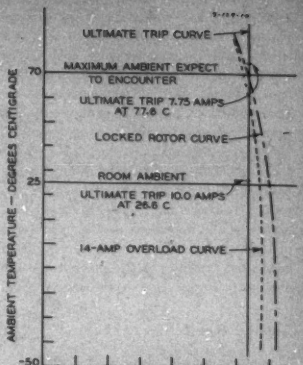


Figure 10. Actual results—inherent protected motor—ambient versus hot-spot temperature for any maximum safe load or overload

7. When using a protected motor, do not undermotor an application.

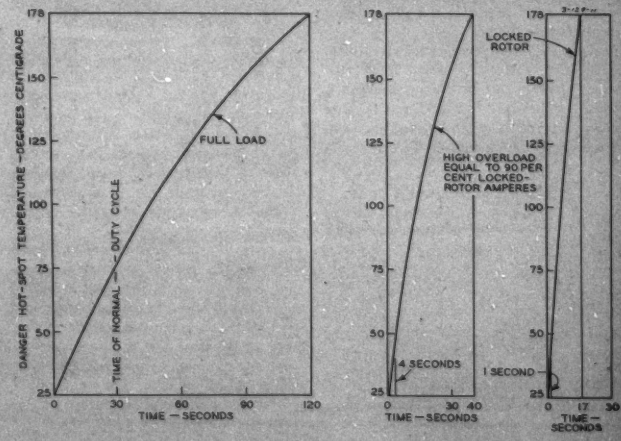
Men's lives depend on the continued functioning of aircraft electric motors. Restricting the output of an electric motor is poor engineering; a burned-out motor is a total loss; protect them so that all allowable output of aircraft electric motors is available to the crews.

Supplement

Since writing this paper, I have had a number of discussions with various people, and as a result of these discussions I have made some theoretical curve sheets which are in this supplement. These curves have particular reference to the results of overprotection and to the results that are likely to occur when one makes an application for locked-rotor protection only.

On curve sheet Figure 11, at the left, is the theoretical time-temperature curve for an intermittent-duty 24-volt d-c motor, run at an ambient of 25 degrees centigrade and with full load current. It is to be noted that the duty cycle is 30 seconds and that it takes 120 seconds for the hot spot to get up to the assumed dangerous temperature of 178 degrees centigrade. From the data on this curve, it is evident that as long as everything

Figure 11. Theoretical time-temperature curves for intermittent-duty 24-volt d-c motor at 25 degrees centigrade ambient temperature



runs normally no protection is required. The motor cannot be overloaded, and it cannot get too hot.

At the extreme right is the theoretical time-temperature curve for locked rotor. Here, we see that the motor will be on the line 17 seconds before the hot spot reaches the assumed dangerous temperature of 178 degrees centigrade.

When a protector is applied to give locked rotor protection only, there is a tendency to set the protector down to as short a time as possible.

In these d-c motors it only takes a fraction of a second for them to come up to speed so that a protector which cuts off at one second would allow ample time for the motor to start and come up to speed, providing there was no excessive load on the motor. A protector with this type of characteristic would give protection for locked rotor, and, if the rotor was definitely locked because of jamming in the mechanism, there is nothing to be gained by leaving the motor on longer than the one second.

In the center curve of Figure 11 we have a theoretical time-temperature curve of this motor when the load is such that the current is approximately 90 per cent of the locked-rotor amperes. Here the motor is running and doing some work, although the speed may be very slow, yet, if kept on the line long enough, the duty cycle could be completed. This would be particularly true if the motor under this running condition were allowed by the protector to run up to its maximum assumed safe temperature of 178 degrees centigrade. In this case, you will note that it would take 40 seconds to attain this temperature. The protector would cut "on" and "off" and the motor would run for a while, and then stand stationary for a while, and then run, and so forth, until the unit had an opportunity to complete the cycle.

On the other hand, if this motor were protected with a protector that cut off at one second under locked conditions, then four seconds would be the maximum that we could expect the protector to let the motor run with 90 per cent of locked amperes, and here we would have such a short "on" cycle that the length of time required for the unit to complete its duty cycle would be so great that it is extremely doubtful if any useful work could be obtained from the motor at this or any other high overloads.

On curve sheet Figure 12, these two types of protector performances are illustrated by the "on" and "off" cycles. In the curve at the top of the page, the protector allowed maximum output of the motor and in the one at the bottom of the page, the protector was applied for locked-rotor protection only (one-second cutoff). By accumulating all of the "on" times, we see that at *A* we have an accumulated running time shown as the result for six cycles of protector operation, whereas at *B* we have the accumulated time for 15 cycles, the 15 cycles having taken place in the same length of time as the six cycles shown.

From experimental work done so far, it appears as if there is considerable likelihood of obtaining the poor performance indicated by applying thermal protectors for locked-rotor protection only. Therefore, it is believed that one of the most important considerations in connection with aircraft electric-motor protection is to make sure that the protector allows the motor to give its maximum capacity under all conditions of load and ambients.

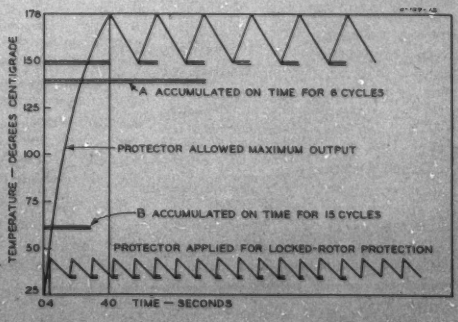


Figure 12. Theoretical time-temperature curves for intermittent-duty 24-volt d-c motor run at 90 per cent locked-rotor amperes

The Testing of Mercury-Arc Rectifiers

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THE design of mercury-arc rectifiers is based, as is that of all electrical apparatus, upon knowledge gained from fundamental principles, test data, and operating experience. Our knowledge of the physical action occurring within the rectifier is very limited. While the fundamental processes which take place in an arc discharge have been quite completely described by physicists,[1] their complexity has prevented their expression in a form usable by the engineer. For this reason rectifier design depends, to a larger degree than does the design of most electrical apparatus, upon experimental data obtained from tests.

Of the actions occurring within the rectifier, the phenomenon of arc-back is particularly important as it plays a dominant role in the testing, rating, and performance of mercury-arc rectifiers. Various theories have been proposed in an endeavor to account for arc-backs, and the more recent of these appear to agree quite well with observations and experience.[2,3] Despite these advances, the causes of arc-back are not yet sufficiently well understood so that the effect of specific modifications in the construction may be reliably predicted.

Special testing procedures are required to meet the unique conditions encountered in rectifier operation. Arc-back behavior is a primary consideration in the formulation of load tests involving the determination of arc-back rate. Some correlation has been observed between duty on the rectifier, condition and construction of the rectifier, and frequency of arc-back, but the occurrence of arc-back is essentially random in nature, not only under definite limiting conditions, but under all conditions of rectifier loading. The determination of arc-back rate from load tests is, therefore, a statistical problem. The magnitude of the problem may be appreciated from the fact that one arc-back per month on a six-anode rec-

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tifier operating at 60 cycles is but one failure per billion cycles. It is obviously impractical to check such performance by operation under normal conditions, so special testing methods must be devised.[1]

The primary purpose of this paper is to describe the procedure used in testing mercury-arc rectifiers during both development and manufacture. Tentative standards for testing rectifiers are covered by report on AIEE Standard 6 for "Acceptance Tests for Metal-Tank Mercury-Arc Rectifiers," issued in 1934. However, these standards do not cover recent developments in testing technique.

The nature of the electrical and mechanical limitations of the rectifier is discussed in an endeavor to provide a basis for the evaluation of results of tests in terms of expected operation in normal service. The basis for the rating of rectifiers is also discussed and data are presented showing the results of tests on standard rectifiers.

Purpose and Scope of Tests

Tests on mercury-arc rectifiers may be classified under three general heads, depending upon the purpose for which they are made; namely, developmental, commercial, and field tests.

Developmental Tests

Since the fundamental knowledge is not sufficiently complete to provide a satisfactory design basis, new rectifier designs are based upon experience gained from previous designs supplemented whenever necessary by tests bearing directly on the problem at hand. Developmental tests may range from general studies of the physical action to specific tests on a full-size sample of the new design.

Examples of such general studies are: heat transfer and the distribution of losses; vapor pressure, and vapor flow; ionization during the inverse cycle; inverse current to the anode; phase occurrence of arc-back; current distribution during the conduction period; magnetic effects; and so forth. Examples of specific tests are: mechanical, electrical, and thermal measurements on new materials and new structural arrangements for component parts, load tests, control tests, and so forth.

The development of a new rectifier design usually requires the construction of a full-size sample. Developmental tests are made on this sample in order to determine the modifications required to obtain the desired performance. The complexity of the physical action and the lack of complete knowledge of the fundamental processes preclude the use of scale models in making rectifier tests.

Commercial Tests

These are tests made on commercial rectifiers during manufacture for the purpose of

1. Checking the quality of manufacture.
2. Determining the characteristics of the rectifier equipment.
3. Checking the over-all performance.

Field Tests

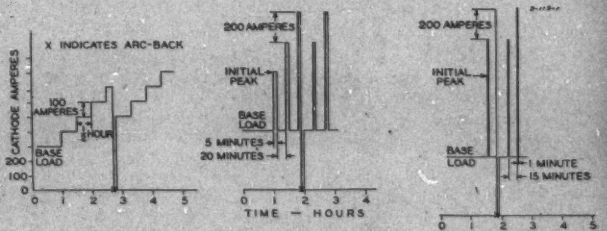
Despite the steady accumulation of rectifier knowledge and experience, it is still not possible to predict or guarantee in advance the exact performance of a rectifier in the field, particularly as regards the frequency of arc-back. Rectifiers of proved ample capacity and good design may operate with excessive arc-backs when first put into service in new installations, and it is sometimes found necessary to make minor adjustments in the field to obtain proper performance.

Field tests are usually directed at factors not covered by the developmental tests, for example, the effects of longer periods of continuous loading than can be undertaken in the factory tests or different service conditions. Furthermore, field tests must be arranged so that they may be carried on concurrently during normal operation.

List of Tests

A list of the more important tests used in the development and manufacture of mercury-arc rectifiers follows:

1. Shop tests.
   Vacuum tightness.
   Degassing.
   Dielectric tests.
2. Load tests.
   Load-limit tests.
   Load runs.
   Duty cycle.
3. Short-circuit tests.
   Current limit.
   D-c short circuit.
   Simulated arc-back.
4. Control tests.
   Pickup action.
   Blocking action.
   Phase control.
5. Performance characteristics.
   Efficiency.
   Voltage regulation.
   Power factor.
   Wave form.



A. Continuous load limit
1. Start at base load specified
2. Increment, 100 amperes every half-hour, approximately five per cent of basic load
3. Increase load until arc-back occurs
4. Reduce load 200 amperes and continue as before
5. Continue until three successive arc-backs are obtained at substantially equal loads, indicating that limit has been reached

B. Five-minute load limit
1. Start at base load two thirds of continuous load limit
2. Initial peak, 200 amperes greater than continuous load limit
3. Duty cycle—20-minute base load, five-minute peak, repeat
4. Increment, 200 amperes on successive peaks
5. If arc-back occurs, reduce load 200 amperes and continue as before until three arc-backs are obtained at limit

C. One-minute load limit
1. Start at base load two thirds of continuous load limit
2. Initial peak—200 amperes greater than five-minute load limit
3. Duty cycle, 15-minute base load, one-minute peak, repeat
4. Increment, 200 amperes on successive peaks
5. If arc-back occurs, reduce load 200 amperes and continue as before until three arc-backs are obtained at limit

Figure 1. Procedure for load-limit tests

Shop Tests

In the manufacture of pumped rectifiers the first tests made upon the com-

pletion of assembly are vacuum tightness and degassing. These tests provide a check on the basic structural quality and condition the rectifier for full voltage operation. Together with the dielectric tests they comprise the ordinary short commercial tests.

Vacuum-Tightness

The vacuum tightness is checked by taking seepage tests. These tests provide a measure of the tightness of the tank materials, welds, insulating seals, and gasket joints and are usually made both before and after degassing. The test procedure consists in evacuating the rectifier, then shutting off the vacuum pumps with the rectifier at room temperature and noting the increase in pressure over a definite period, usually six hours.

Degassing

While the rectifier degassing may be considered an essential part of the manufacturing process, inasmuch as the rectifier must be conditioned before it will operate at full voltage, the degassing operation also serves as a test of various features of the rectifier. For example, it provides a further check on the soundness of the welds, as the steel parts of the rectifier vacuum tank are heated to operating levels for the first time. A weak weld which appeared tight on the first seepage test may show a leak on the second seepage test. The time required for degassing is a measure of the pumping speed of the vacuum pumps. Some indication of the current capacity of the component parts of the rectifier assembly may be obtained by observing the temperatures of the various parts during degassing. The operation of the cooling system may also be checked during degassing since the rectifier losses at any specified current are substantially the same as during full voltage operation.

Dielectric Tests

High-voltage tests are made in the same manner as for most electrical apparatus using a 60-cycle alternating voltage. Such tests provide a check on the correctness of assembly and the soundness of the solid insulation.

Present AIEE Standards[3] call for the application of high-voltage tests after the rectifier has been thoroughly evacuated and degassed. It is not always possible to make tests under this condition because of the occurrence of breakdowns resulting from glow discharge. The voltage required for breakdown between electrodes in a vacuum may differ considerably from that required for breakdown at atmospheric pressure. Where difficulty of this kind is experienced, it has been the usual practice to make dielectric tests with the rectifier filled with air at atmospheric pressure.

Numerous attempts have been made to correlate the high-voltage break-down characteristics of a rectifier with the occurrence of arc-backs. Tests have been made with an alternating voltage and also with a negative direct voltage on the anode, increasing the voltage until breakdown occurred. Measurements of insulation resistance have also been made. While it is possible to determine the insulation strength and other characteristics of the solid insulation by such tests, they give no indication of the rectifier performance as regards the occurrence of arc-backs.

Load Tests

The purpose of load test on rectifiers is to determine their quality in terms of capacity and reliability. The simple structural abilities are readily evaluated by loading the rectifier and making thermal and mechanical measurements. But the arc-back rate cannot be determined by operating at normal loading because of time limitations. Theory indicates and experience has shown that the performance of a rectifier under normal conditions may be gauged from tests made under more severe conditions of loading.

There are two general types of load tests. One is the accelerated load test, or "load-limit test" as it has been termed, which is used primarily to determine the capacity of the rectifier. The other is the "load-run" or duty-cycle test, which is used for checking the reliability and quality of manufacture. The inherent difference between these tests lies in the method of loading. The procedure in the case of the accelerated test is to increase the loading gradually until failure occurs, either structural or arc-back, while that for the load-run test is to maintain a predetermined loading for a definite period and observe the operation.

The loading or duty on a rectifier involves a number of factors, among which are the following:

1. D-c voltage.
2. Load current.
3. Amount of phase control.
4. Type of circuit and circuit reactance.
5. Duration of loading.

All of these factors must be considered in the application of load tests. However, the usual procedure is to make tests at a given d-c voltage, such as 600 volts, and vary the loading by changing the load current. The amount of phase control may also be varied. Tests are usually limited to a single d-c voltage and one transformer circuit.

A further factor which is usually varied during load tests is the rectifier control temperature as the rectifier performance is a function of its temperature.

Load-Limit Tests

Load-limit tests are made by applying a gradually increasing load on the rectifier until failure occurs, either structurally or because of arc-back. A typical loading procedure which has been used successfully in the development of a number of new rectifiers is shown in Figure 1.

Several factors must be considered in the choice of loading procedure. One of the more important of these is the duration of loading. The thermal storage capacity of a rectifier is small relative to its losses and the thermal time constant is about $\frac{1}{2}$ to 1 hour. A one-half-hour interval was, therefore, selected for the continuous test. Shorter intervals were chosen for the five-minute and one-minute tests on the basis that substantially normal temperatures may be obtained by operating at reduced load between peaks. A set of continuous five-minute and one-minute load-limit tests using these time intervals may usually be made in an elapsed time of two or three days.

Another factor is the effect of aging upon rectifier performance. It is well known that the arc-back rate on a rectifier, during initial operation at full voltage immediately following degassing, may be greater than that obtained subsequently after several weeks' or months' operation. This improvement in operation is due to further conditioning occurring under load. This conditioning effect is hastened by operation at heavy loads such as are applied during load-limit tests, and it is, therefore, desirable to obtain several arc-backs at approximately the same load values in order to insure that the load limit has been reached.

It is not always possible to increase the rectifier loading sufficiently to obtain arc-backs. In some types of construction, parts of the rectifier, particularly those in the arc path, may be permanently damaged by excess loading, and this damage may occur before arc-back is obtained. In multianode rectifiers the cathode construction is frequently limiting. However, it has been found desirable, wherever practical, to design the

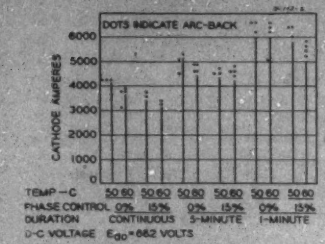


Figure 2. Results of load-limit tests on three ignitron tanks

rectifier so that damage of this kind will not occur, and the load limit is fixed by arc-back. A sturdy construction, capable of operation until arc-back occurs, facilitates testing considerably and permits full attention to the problem of arc-back.

The results of load-limit tests on three ignitron tanks are shown in Figure 2. The standard rating for a rectifier unit consisting of six of these tanks is 2,500 kw at 625 volts. The procedure described in Figure 1 was used in making these tests.

Single anode rectifiers like the ignitron or excitron, may be tested in sets of three since each tank is separate and operates independently. The circuit action, insofar as the voltage and current waves impressed on the anodes are concerned, is substantially the same when three tanks are operating on a single wye as when they are operating as a part of a multiple rectifier, for example, in a double-wye circuit. Three-anode operation facilitates rectifier testing considerably and provides a substantial reduction in time, labor, and power requirements. A large amount of the developmental work on the ignitron has been carried out on three tank units.

The results of load-limit tests on a six-anode multianode rectifier are shown on Figure 3. This rectifier has a standard rating of 1,500 kw at 3,000 volts. Although differing in detail, the procedure used for this test was similar to that already described.

In the case of multianode rectifiers, it is necessary to load the complete rectifier, inasmuch as the cathode and tank are common to all the anodes, and the general physical action in the tank is a function of the cathode current. Also, the ionization attributable to current in one anode affects the neighboring anodes. However, a reduction in the power capacity required for testing a multianode rectifier may be effected by passing current through some of the anodes at low voltage on degassing connection.

The effect of temperature upon rectifier capacity is clearly shown by the load-limit tests for the multianode rectifier, Figure 3. These curves indicate that there is an optimum temperature at which the rectifier capacity is a maximum and that the capacity decreases at higher or lower temperatures. Research[4] has shown that in the lower part of the temperature range the rectifier capacity is defined by a "current limitation" and the maximum current which the rectifier can carry is that which utilizes all the molecules in the mercury vapor as positive ions to neutralize the space charge. When this current is exceeded, the arc drop increases abruptly and arc-back ensues. In the upper part of the temperature range arc-backs occur as a result of voltage breakdown because of high mercury-vapor pressure. The voltage which the rectifier will withstand without arc-back decreases as the vapor pressure increases with rise in temperature. At the higher temperature the rectifier capacity is defined by a "voltage limitation." It is generally desirable to operate a rectifier at as high a temperature as possible without incurring arc-backs.

Load Runs

Load runs are made by applying a predetermined loading for a definite period and observing the operation, for example, counting the number of arc-backs which occur. Such runs are usually made with a constant loading applied for a period of 12 or 24 hours. Load runs at rated load or at loadings in excess of rating provide a check on rectifier performance under conditions approximating those encountered in service. While the period of loading is too short to determine the arc-back frequency on a successful rectifier and the service conditions may not be fully duplicated, such tests do indicate the maximum arc-back rate likely to be incurred in service.

In cases where load-limit tests cannot be applied because of structural or thermal limitations, lack of testing facilities, and so forth, the rectifier capacity may be determined by means of load runs. The procedure consists in making a series of load runs, increasing the loading on successive runs and determining the arc-back rate for each.

Commercial tests on rectifiers include load runs when complete tests are required. They may be made either with the transformer being furnished for installation with the rectifier, or with a test transformer. However, such tests are costly and furthermore do not assure successful operation as regards arc-backs.

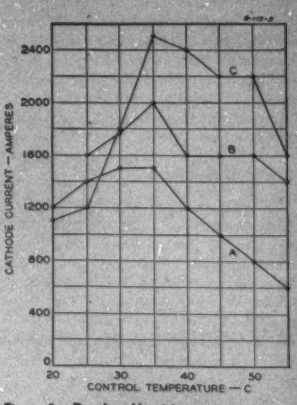


Figure 3. Results of load-limit tests on 3,000-volt multianode rectifier

Curve *A*. Continuous load limit with current increased 100 amperes every two hours

Curve *B*. 20-minute load-limit with current increased 200 amperes on successive trials; 40-minute operation at 500 amperes between peaks

Curve *C*. Five-minute load limit with current increased 200 amperes on successive trials; 25-minute operation at 500 amperes between peaks

For this reason, when a rectifier of a proved design or a large number of rectifiers of the same design are furnished and only short commercial tests are required, load runs may safely be omitted. Often load runs are made on a sampling basis, for instance, by testing every tenth rectifier.

Duty Cycles

The operating conditions incurred in electrochemical service are essentially the same as those obtained during load runs. In cases where the rectifier will operate under variable loads (as for example, railway or steel mill service), it is frequently desirable to make tests, applying a duty cycle simulating the actual operating conditions. This is particularly true where service conditions depart considerably from normal.

Faulty operation may be encountered in rectifiers at light loads as well as under overload conditions. One example of such trouble is mercury condensation on the rectifier anodes at low ambient temperatures with exposure to a cold air flow. Such condensation causes arc-backs on starting. Failures may also arise from the varying temperatures with changing load, which result in mechanical failure attributable to the movement of parts

during expansion and contraction. Another difficulty which may be encountered is failure to obtain stable or constant temperature control with varying loads. Duty cycles simulating the conditions obtained in service provide a further check on the rectifier operation prior to installation, and assist in the elimination of such minor difficulties.

Determination of Rectifier Capacity

Many types of electrical apparatus are designed to meet definite temperature rise limits, for example, a 40 degree centigrade rise.[7] A principal determining factor in establishing temperature rise limits is the thermal endurance of the insulating materials, although other factors must also be considered. Since the physical deterioration of insulation under the influence of time and temperature increases very rapidly with temperature, the choice of temperature rise limit bears directly upon the probable life and reliability of the apparatus. The concept of temperature rise as a basis for rating is a convenient and useful aid in the design of most electrical apparatus.

In the case of mercury-arc rectifiers the construction is usually such that time and temperature produce no appreciable deterioration and the life is so long that replacement will probably not be required before obsolescence occurs. The principal economic considerations are operating cost and reliability. These factors cannot be gauged from any measurement of temperature rise. However, the reliability may be expressed directly in terms of the frequency of arc-back while the cost factors, such as rectifier power losses and maintenance, are also a function of the arc-back rate. Thus, it follows that rectifiers should be rated on a basis of arc-back frequency.

A high arc-back rate results in increased maintenance on protective switchgear, increased strain on transformer insulation, added hazards to operation, and interruption in service. The allowable arc-back rate depends upon the class of service. Many rectifier applications are of such character that an arc-back frequency of the order of one per month is acceptable, and 10 to 30 times this frequency for short periods does not exact any considerable economic penalty. Most railway, electrochemical, and industrial installations fall in this class. There are other applications where continuity of service is so important that an arc-back rate of more than one per year is not acceptable. Public utility installation involving essential service and industrial installations supplying power to gear cutting machines are examples of such applications. The two classes of service appear to necessitate different standards of performance.

Rectifiers having an arc-back rate of the order of one per year or less are usual at the present time for 250-volt service. Experience has shown that such performance is usually obtained when a 600-volt rectifier is operated at 250 volts. While it is possible to build rectifiers for 600-volt service having an arc-back rate not exceeding one per year, it appears that there would be certain economic penalties since the construction will entail considerable improvement in baffling with resultant arc losses, reduction in rating for a given size, and increased complexity of control.

An important consideration in the operation of a rectifier is its stability as regards arc-back. It must be recognized that an acceptable arc-back rate is not always obtained when the rectifier is first put into service. When trouble is experienced on a rectifier installation because of high arc-back frequency, the question is immediately raised, will there be progressive deterioration with an increase in arc-back frequency until the equipment becomes inoperative? Experience to date indicates that while the arc-back frequency may exceed the acceptable or desired value resulting from a large variety of causes, stable operation is generally obtained at a definite arc-back rate.

Short-Circuit Tests

Knowledge of the short-time current capacity of a rectifier is essential to the proper application of protective switchgear, and the choice of system reactance to limit fault currents. Short-circuit tests are of three general types: namely, single-cycle current limit, d-c short circuit, and simulated arc-back tests.

Current-Limit Tests

Basic data regarding the rectifier fault current capacity may be obtained by passing a single cycle of current through one anode with the d-c circuit shorted and increasing the magnitude of this current on successive trials until failure occurs. The behavior of the rectifier under these conditions is determined from oscillographic records.

The specific procedure for making current-limit tests is as follows: A single anode of the rectifier is connected to one phase of the rectifier transformer with the d-c leads short-circuited. The usual protective switchgear in a-c and d-c circuits may be provided but is arranged for delayed operation. The transformer is energized, but conduction is prevented either by negative grid voltage in the case of the multianode rectifier or by absence of ignitor excitation in the case of the ignitron. A single cycle or fault current may be caused to flow by energizing the grid or ignitor for one cycle by means of a welder control. The magnitude of the fault current is controlled by varying the phase of firing or by placing a reactance in series with the transformer circuit. In making these tests, the magnitude of fault current is gradually increased until arc-back occurs. Tests are usually made at several temperatures. Tests may also be made with more than one cycle of fault current.

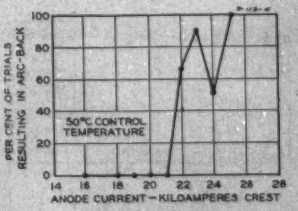


Figure 4. Results of current-limit tests on ignitron rectifier

The results of current-limit tests on a standard ignitron tank are shown in Figure 4, while Figure 5 is a typical oscillogram of a successful single cycle current-limit test.

Failure of control may occur in the course of current-limit tests as well as arc-backs. Control failures may be of various types. For example, in the case of ignitron rectifiers, the anode may fire during the cycle succeeding the conducting cycle without the ignitor being reenergized. In multianode rectifiers where voltage is applied to all the anodes but only one anode is permitted to fire, the other anodes may also fire because of failure of their grids to block. The control characteristics will be more fully described in the section on control tests.

D-C Short Circuit

D-c short-circuit tests are made for the purpose of checking

1. The ability of the rectifier to withstand the fault currents.
2. The operation of the protective switchgear.

The testing procedure consists in connecting a definite low resistance across the

d-c leads of the rectifier by means of a contactor or high capacity switch. The resulting short-circuit current may be interrupted by the rectifier cathode breaker, anode breaker, or the oil circuit breaker in the transformer primary circuit. Or alternatively, the current flow may be suppressed by action of coptrol grids or ignitors. The magnitude and duration of the short-circuit current as well as the operation of the protective switchgear may be checked by oscillograph.

The high currents flowing through the rectifier under short-circuit conditions cause the liberation of gas from the anode and other parts in the arc path. A measure of the speed of the vacuum pumps may be obtained by noting the time required to remove the gases liberated dur-

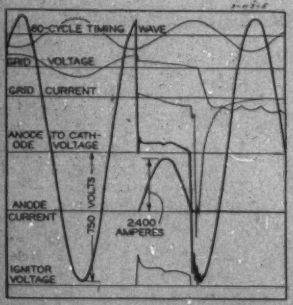


Figure 5. Typical oscillogram of successful single-cycle current-limit test (with negative voltage applied to grid to block firing on succeeding cycle)

ing the short circuit. Short-circuit tests also provide a check on the sturdiness of the rectifier tank and the external bus structure and their ability to withstand short-circuit stresses. While the rectifier must be able to withstand repeated short circuit without damage, it is not essential that it be able to operate without arc-back under the most severe conditions.

Simulated Arc-Back

Since the switchgear furnished with rectifiers is specially selected to provide protection during arc-back it is often desirable to check its effectiveness by direct tests. This may be done by applying a short circuit between one anode of the rectifier and its cathode by means of a contactor or other shorting device, while the rectifier is operating under load. Such a short circuit simulates the conditions obtained when one anode of the rectifier arcs back. The resulting operation of the rectifier and its protective equipment is determined by taking oscillographic records.

Simulated arc-back tests may be made with the rectifier operating on either a water-box load or on a live load such as a motor generator set. In the latter case the load will feed current into the fault. The same is true where two or more rectifiers operate in parallel. Simulated arc-back tests are usually made only where complete tests are required. Because of the limitations of factory facilities, such tests are frequently made in the field.

Control Tests

The starting of anode conduction in a rectifier is controlled by the auxiliary electrodes, such as starting and excitation anodes, grids, and ignitors. In general, these may be arranged to perform the following three functions:

1. To provide the conditions required for anode conduction; namely, a source of electrons (cathode spot) at the cathode, the propagation of ionization in the mercury vapor in the arc path, and a flow of electrons to the anode. These conditions determine the pickup action.
2. To prevent the firing for one or more cycles by exerting a blocking action.
3. To delay the starting of conduction for a definite time each cycle so as to obtain phase control.

Rectifier control requirements vary from those of the simple shunt rectifier without control to those of a fully controlled rectifier with phase control for varying the output voltage and firing control for starting and stopping. The purpose of control tests is to obtain data regarding the various factors entering into the control action, and to check the effectiveness of the control means under the various conditions of operation.

Pickup Tests

Pickup tests are primarily of value in determining the excitation requirements of the rectifier and checking its light load operation. Pickup tests may be made by operating the rectifier at full voltage on a high resistance or counter electromotive force load. The pickup voltage is determined by varying the load resistance or the value of counter electromotive force voltage and observing the d-c volt-ampere characteristics of the rectifier.

In multianode rectifiers the arc is established at the beginning of operation by means of the starting anode and maintained during operation by the excitation anodes which are usually continuously excited. The excitation arc must provide sufficient ionization to assure pickup of each of the main anodes when its voltage becomes positive. When the rectifier is equipped with grids, the grid may also be excited so as to assist anode pickup. In ignitron rectifiers the arc is established during each cycle by means of the ignitor. The ignition current must both initiate the cathode spot and provide sufficient ionization to pick up the anode. As in the case of multianode rectifiers, the pickup characteristics are dependent upon the grid excitation.

The voltage range of the auxiliary power supply is an important consideration in the determination of rectifier excitation requirements. Low voltage is frequently encountered in normal operating service. Sufficient excitation must be provided to obtain satisfactory pickup at the minimum expected auxiliary voltage.

Poor pickup characteristics may result in a variety of troubles. Where several rectifiers operate in parallel and one rectifier is taken out of service, difficulty may be experienced in causing it to pick up and share load with the other rectifiers when it is reconnected to the bus. When rectifiers are installed for automatic operation, the control relay is sometimes arranged so that its action is dependent upon the pickup of the rectifier. In supervisory operation reliable pickup is essential to good operation.

The pickup characteristics of a rectifier may be influenced considerably by the condition of the rectifier tank. For example, it has been found that rectifiers which picked up satisfactorily when new gave trouble as operation was continued and the tanks became freer from gas because of aging. Also, the control temperature and the temperature distribution over the rectifier tank may have an important bearing on the pickup behavior. In multianode rectifiers, poor pickup may result from leakage resistance between rectifier tank and negative ground since the rectifier tank acts as a grid and tends to block the firing of the main anode.

Blocking Tests

Blocking action may be applied under two conditions. In one case it is used to prevent conduction while the rectifier is being placed in service. In the other case it is used to interrupt the rectifying action either at normal loads or under fault conditions. Effective blocking action is more difficult to obtain in the latter case, as the ionization carries over from the conducting cycle.

The minimum blocking voltage required on the grids of a rectifier in order to prevent conduction during starting may be measured by applying a positive d-c voltage to the anodes and a variable negative d-c voltage to the grids. The voltage on the grid is varied until the anode fires. This type of test may be made on either single-anode or multianode rectifiers. A typical grid characteristic for an ignitron is shown on Figure 6.

The effectiveness of the b'ocking action in interrupting the rectifier current under fault conditions may be determined by means of the same procedure used in making current-limit tests.

Phase-Control Tests

The output voltage of a rectifier may be controlled by varying the phase of the voltage applied to the grids or ignitors. For proper performance of this control function it is essential that a definite relation be accurately maintained between the control voltage applied to grid or ignitor and the anode firing.

There are two possible causes of control failure, namely, loss of control or early firing of the anode, and delay in anode pickup. Some of the factors which may cause control failure are: high load current, high or low temperature, foreign gases, faulty construction. In order to determine the grid or ignitor control characteristics it is necessary to operate the rectifier on load under the various conditions and observe or record the voltage and current characteristics of the control electrode and the anode by means of an oscillograph.

Loss of control is incurred when the anode fires either before or without the application of a control impulse. This may occur in a multianode rectifier when the grid does not prevent ionization reaching the anode and so permits the anode to fire when it becomes positive. In ignitron rectifiers the positive anode voltage acting on the residual ionization may initiate a cathode spot before the ignitor is energized.

A variable time may exist between the firing of the grid and the main anode under certain conditions. This phenomenon has been noted on both multianode and ignitron rectifiers. The difference in time of firing may be reduced to a negligible amount or eliminated by proper choice of firing circuit constants and operating conditions.

The control characteristics of the rectifier unit may be checked by making voltage-regulation tests with specified phase-control settings and comparing the measured output voltages against the calculated values.

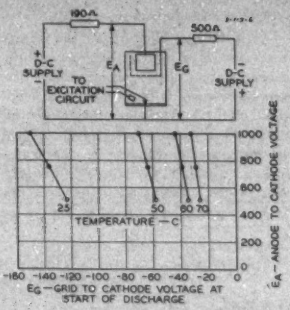


Figure 6. Grid-blocking characteristic of ignitron rectifier

Performance Characteristics

The performance characteristics of a rectifier unit may be determined by direct measurement. However, such tests require the assembly of the complete equipment and present other practical difficulties. The performance characteristics are, therefore, ordinarily determined from calculations based on measurements of rectifier and transformer losses and transformer reactance.

Efficiency

The "directly measured efficiency" is obtained from simultaneous measurements of input and output power. Elaborate precautions must be taken in order to obtain accurate results using this method.[8]

The "conventional efficiency" is obtained from the component losses determined from loss tests. Since most rectifiers have a high efficiency and the losses are only a small part of the total power, a given error in the measurement of the losses does not affect the efficiency as much as the same percentage error in the measurement of total input and output. For this reason the conventional efficiency method is preferred.

The losses incurred in a rectifier equipment are classified as follows:

(*a*). Rectifier arc-drop loss.

(*b*). Rectifier auxiliary losses.

(*c*). Rectifier transformer losses.

Methods for measuring these losses follow:

Arc-Drop Loss

Various methods have been proposed for the measurement of the rectifier arc-drop loss. See the report on AIEE Standard 6.[1] Of these, the oscillographic method has found widest acceptance. However, this method is open to the objection that the rectifier arc losses when operating at low voltage differ from those obtained in full voltage operation since the anode current wave forms are not the same. In order to overcome this objection an improved oscillographic method has been devised which permits operation of the rectifier at full voltage during arc-drop measurements.

The improved oscillographic method employs a noninductive external resistor connected in series with the oscillograph element and a small mercury-arc-rectifier tube (or dry-type rectifier) in shunt with the oscillograph element as shown in Figure 7. The shunting rectifier is connected so as to limit the voltage across the oscillograph element during the inverse period. This voltage may be further reduced by means of a battery connected in series with the shunting rectifier.

A typical arc-drop oscillogram of a large ignitron is shown in Figure 8. This oscillogram shows the arc-drop voltage

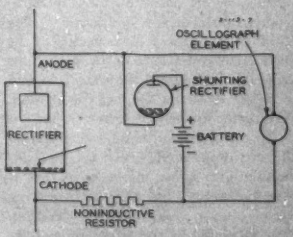


Figure 7. Schematic diagram of oscillograph circuit for measuring rectifier arc drop

and the anode current. The anode current wave is used to determine the limits of the conduction period. On large pumped rectifiers, there is considerable inductive effect in the rectifier tank itself which results in an inductive voltage during the commutation periods. This inductive voltage is superimposed on the actual arc-drop voltage so that the limits of the conduction period cannot be determined directly from the arc-drop voltage wave.

The average arc-drop voltage is obtained from the oscillogram by determining the average ordinate of the segment of the arc-drop voltage wave within the limits of the conduction period by means of a planimeter. The arc-drop loss is equal to the product of this voltage

multiplied by the total cathode current measured simultaneously with the taking of the oscillogram.

On small rectifiers where inductive effects are negligible and the arc-drop voltage wave is essentially flat, the average arc-drop voltage may be measured directly on a d-c voltmeter by using a comparison method. In this method the arc-drop voltage wave is observed on a cathode-ray oscillograph, and the amplification is adjusted so as to obtain a suitable deflection on the screen. The oscillograph element is then switched to a calibrating circuit consisting of a potentiometer with a d-c voltmeter. The oscillograph element is connected to the voltmeter terminals, and the d-c voltage drop is adjusted until the same deflection is obtained on the oscillograph as when viewing the arc-drop voltage.

The oscillographic method of measuring the arc drop in rectifiers has one advantage over other methods, in that it permits observation of the rectifying action during full voltage operation. This is useful in the study of rectifier action in the course of developmental or field tests.

Auxiliary Losses

The auxiliary losses are determined by measuring the input power to the auxiliaries.

Rectifier Transformer Losses

No-Load Loss Tests. Tests for no-load losses may be made in accordance with the standard methods used for other transformers.

Load Loss Tests. The load losses for rectifier transformers may be determined by several methods. One of these is described in the report on AIEE Standard 6.[4] This method requires tests with two or more connections for some circuits. An alternative method which requires only a single connection is described in Appendix A.

Voltage Regulation

As in the case of efficiency, the voltage regulation of a rectifier unit may be determined from direct measurement. The procedure consists in measuring the output voltage at various values of output current with a constant voltage applied to the primary winding of the transformer. Since the reactance of the supply system effects the apparent regulation of the rectifier unit, the regulation cannot be determined accurately by direct measurement. Therefore, the regulation is ordinarily determined from values of output voltage calculated by subtracting the voltage drops in the rectifier and transformer from the rectifier no-load voltage. The method of calculating the output voltage is described in Appendix B.

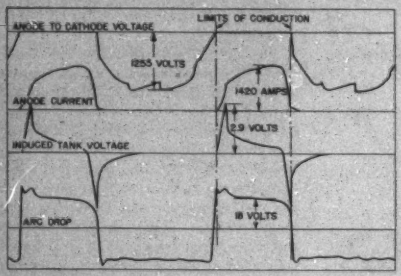


Figure 8. Typical oscillogram of arc drop in ignitron rectifier

Inductive voltage measured by passing anode current through duplicate tank having copper bus connecting anode direct to bottom of tank in mercury pool

Power Factor

The power factor of a rectifier unit may be determined from simultaneous measurements of the input power and input volt-amperes. The reactance of the supply system affects the power factor in the same manner as it does the regulation. For this reason direct measurement of power factor under test conditions must be considered approximate. The power factor is generally determined by calculations based on separately measured characteristics of the rectifier and transformer such as the transformer reactance and magnetizing current.

Wave Form

The harmonic composition of the rectifier input and output waves may be determined either by direct harmonic measurements or from analyses of oscillograms. The over-all effect of all the harmonics may also be determined from telephone-influence-factor measurements The wave form of a rectifier is of importance primarily as one of the factors of which a knowledge is desirable in evaluating the influence of the power system on neighboring communication circuits. Since the harmonics produced by a rectifier are affected by the reactance of both the a-c and d-c power circuits to which the rectifier is connected, measurements made under test conditions in the factory may differ from those obtained in the field under actual operating conditions because of the different constants in the two circuits. Methods are available for calculating with reasonable accuracy the wave shape of the voltage and the current in both the a-c and d-c sides of a given rectifier installation when the circuit constants are known.[9]

Testing Facilities

Extensive facilities are required for the testing of mercury-arc rectifiers. There must be provided a complete power system capable of supplying and loading the rectifier to the limit of its capacity, an auxiliary power supply together with the essential rectifier auxiliaries, and an extensive assortment of both standard and special instruments. An arrangement of the rectifier test equipment is shown in Figure 9.

The a-c power system used for testing rectifiers must be of sufficient capacity to maintain substantially sinusoidal wave shape at full rectifier loading and also to give short-circuit currents approximating those obtained in service. Inasmuch as rectifiers must be operated at and above their rated loads for considerable periods during the course of tests, motor generator sets arranged to pump back into the

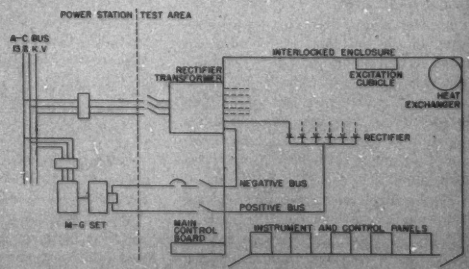


Figure 9. Arrangement of rectifier test equipment

a-c system are used for absorbing the rectifier output.

The generous use of oscillographic instruments is essential in rectifier testing. Oscillographic equipment must include both magnetic and cathode-ray types and must provide facilities for both visual observation and photographic recording. Special instruments and special instrument techniques have been developed for use in rectifier testing. Of these perhaps the most important are the arc-back indicators, the memory oscillograph, and the technique for measuring arc drop. The full use of all available instruments and the development of new instruments is essential to further progress in the analysis of rectifier action.

Appendix A. Transformer Load Loss

The transformer losses may be determined from measurements made by short-circuiting all secondary windings and passing rated sinusoidal current at rated frequency into the primary windings. The losses absorbed by the transformer during this test represent the full-load copper losses when the current is sinusoidal. The total copper losses when operating with non-sinusoidal current in rectifier service may be calculated from this test value as follows:

Symbols

The symbols used in the formulas are defined as follows:

I_p = rated primary current
I_s = rated secondary current

(These primary and secondary currents are the rms values of current for a flat top wave without overlapping.)

R_p = ohmic resistance of primary winding
R_s = ohmic resistance of secondary winding

(These resistances are for copper temperature of 75 degrees centigrade.)

K_p = rated kilovolt-amperes of primary windings
K_s = rated kilovolt-amperes of secondary windings
n = turn ratio
P_1 = losses absorbed by transformer during test
P_2 = ohmic losses for sinusoidal current
P_3 = stray load losses for sinusoidal current
P_4 = ohmic losses for rectangular current
P_5 = total load losses for rectangular current

Calculation of Stray Load Losses

The losses absorbed by the transformer during the test, P_1, should be corrected to a temperature of 75 degrees centigrade.

The current in the short-circuited secondary winding of the transformer during the test will be $I_s' = nI_p$ with rated sinusoidal current of value I_p flowing in the primary winding. The ohmic losses for sinusoidal currents of these values, P_2, are:

$$P_2 = (I_p)^2R_p + (I_s')^2R_s = I_p^2(R_p + n^2R_s)$$

The stray load losses for sinusoidal currents, P_3, are then:

$$P_3 = P_1 - P_2$$

It is assumed that these stray load losses are the same whether the current of the transformer is sinusoidal or has the rectangular wave form obtained during the normal operation of the rectifier. This assumption is justified by a large number of tests carried out by different methods, the variations not being larger with this method than with other methods. With this method, however, it is assumed that the requirements of the various windings of the transformers as to symmetry are entirely fulfilled.

Calculation of Total Load Losses

The ohmic losses for rectangular current, P_4, which are obtained during normal service of the rectifier are:

$$P_4 = I_p^2R_p + I_s^2R_s$$

The total load losses of the transformer during normal service of the rectifier, P_5, are equal to the sum of the ohmic and stray load losses and:

$$P_5 = P_3 + P_4 = P_1 + I_s^2R_s\left[1 - \left(\frac{I_s'}{I_s}\right)^2\right]$$

$$= P_1 + I_s^2R_s\left[1 - \left(\frac{K_p}{K_s}\right)^2\right]$$

When making load-loss tests on the rectifier transformer, the interphase transformers and anode reactors should be disconnected.

For interphase transformers in which the load current is almost entirely direct current, the d-c resistance of the winding may be used in computing the load loss.

Appendix B. Rectifier Output Voltage

The formula for the calculation of the d-c voltage of the rectifier unit at a specified load current is:

$$E_d = E_{do} - E_x - E_r - E_a$$

where

E_d = d-c voltage at the specified load current
E_{do} = theoretical d-c voltage (This is the voltage which would be obtained at no-load with no phase control. It is the voltage obtained at the intersection of the regulation curve projected to the zero load line, neglecting the increase in voltage at light load.)
E_x = commutating reactance voltage drop
E_r = resistance voltage drop
E_a = arc voltage drop

The theoretical d-c voltage and the voltage drops may be calculated by using the following formulas:

Theoretical d-c voltage $E_{do} = \sqrt{2}E_s\frac{P}{\pi}\sin\frac{\pi}{P}$

Commutating reactance voltage drop

$$E_x = \frac{I_cX_cP}{2\pi}$$

Resistance voltage drop $E_r = \frac{W}{I_d}$

in which

E_s = secondary line to neutral voltage of rectifier transformer (rms value)
P = number of phases in simple rectifier
I_c = direct current commutated
X_c = commutating reactance in ohms (line to neutral)
W = load losses of main and interphase transformers
I_d = d-c load current

The commutating reactance X_c, attributable to the main transformer, may be measured by short-circuiting the primary windings and passing sinusoidal current at rated frequency between two secondary anode leads between which a transfer of current occurs during commutation. The commutating reactance anode-to-neutral is obtained by dividing one half of the measured impedance voltage by the applied current.

The transformer load loss W may be determined by the method described in Appendix A.

The method for determining the arc-drop voltage E_a is described in the section on efficiency tests.

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A New-Type Carrier Relay Protection

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THE Hydro-Electric Power Commission of Ontario and the Beauharnois Light, Heat, and Power Company have placed in service recently a new type of power-line-carrier equipment. Channels for high-class interterminal communication are combined with other channels which provide a transfer of impulses for use with the relaying on transmission lines, giving a desired improvement in the speed of operation.

Stability Problem

The 220-kv 25-cycle system of the Hydro-Electric Power Commission is shown in Figure 1, and has been described in the AIEE Transactions.[1] In the earlier paper a record of experience as to line faults was presented and analyzed. The problem of relaying in relation to transient stability was discussed. It was pointed out that studies on an a-c network calculator and operating experience indicated that, in order to maintain stability at the normal line loadings of 150,000 to 170,000 kw per main line, it would be necessary not only to clear two-phase-to-ground and three-phase faults at the line terminal nearest to the fault in 0.2 second approximately but also to open the breakers at the remote terminal simultaneously or in 0.25 or 0.3 second at the most. If this could be accomplished, transient stability would not be a problem on this system which carries an important industrial load of 600,000 to 650,000 kw in large centers of population.

The original basic scheme of phase relaying on the four main 220-kv trunk lines, as stated in the earlier paper, consists of directioned two-stage impedance relays of a conventional type. The first stage operates in one cycle (0.04 second) or less for all faults within the 80 to 90 per cent of the line adjacent to the relays. The second range, covering the whole line and overlapping into the contiguous line sections, is set to operate in 12 to 20 cycles (0.5 to 0.8 second), thus being time selective with the instantaneous relays on these sections. This basic relaying scheme has proved very successful during the development period of the system when loads were lighter; but with present loadings it will be seen that it does not meet the requirements for stability, because clearance is delayed too long at the remote terminal for faults located within the 10 to 20 per cent section at the end of a line. It will be noted also that the line from Beauharnois to Chats Falls is tapped for the infeed from the MacLaren-Quebec Power Company, thus presenting a problem in distance relaying. Moreover, there are two short line sections which have impedances at 25 cycles that are too low for best results with plain distance relaying.

Regarding the long lines, there was doubt as to the desirability of depending on the transmission of a blocking signal to prevent incorrect tripping. Therefore, a carrier relaying system was proposed which could be applied to any or all types of impedance relays without changing their normal use. Since the carrier relaying feature should be supplementary to the original relaying system, the failure of the carrier link should not in any way affect the normal operation of the distance impedance relays which use time delay to select the faulted line. The carrier feature should provide only a speed-up in the relay action.

When the first stage distance relays are set to operate for faults which are within the 80 to 90 per cent of the line adjacent to the relays, the carrier protection is unnecessary except for faults which are in the 10 to 20 per cent sections at the ends of the line. The latter are seldom more than 20 per cent of the total number of line faults. Therefore, the addition of carrier as a protection or improvement in the protection on any transmission system should be balanced against this 20 per cent of the faults. If the carrier should fail to operate for any cause whatsoever, only 20 per cent of the total system faults would be affected adversely, and in no case would the incorrect operation or failure in the carrier system be detrimental to the relay system because failure only increases the clearing time for faults in the end sections of the line.

There existed also the problem of communication between the Beauharnois terminal and the commission's plants at Chats Falls and Leaside. Paugan, Chats Falls, Leaside, and stations of the 110-kv system had been interlinked by the commission's overhead telephone lines, but no such provision had been made for MacLaren or Beauharnois. It was desired to link these terminals, particularly the large source at Beauharnois, with the rest of the system by a suitable communication channel which could be of the power-line-carrier type.

Requirements of Carrier System

The relay system should use the directioned instantaneous relay, which protects most of the line, to set up the trip circuit for its own breakers. At the same time this operation would cause an impulse to be sent to the remote end to by-pass the timer on the second impedance range, thereby giving clearances at both ends of the line which are sufficiently near to simultaneous operation to meet the stability requirements. In this scheme, it is not necessary to depend on the passage of the carrier impulse to prevent tripping on external faults; therefore, it would be inherently safer and preferable to the blocking scheme.

The impulse for relaying purposes on one line might be produced by a single frequency or tone in the audio range,

Figure 1. High-voltage lines in the 25-cycle system

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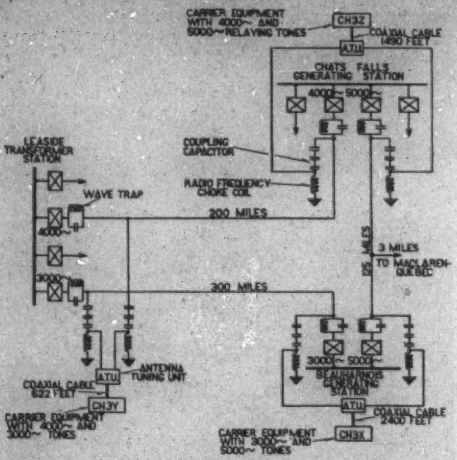

Figure 2. Arrangement of carrier equipment and tones for relaying

which is used for amplitude modulation of the carrier. A separate tone would be assigned to each high-voltage line. One tone generator for transmitting and one tone filter for receiving are required at each end of a protected line, because the impulse for use with the protective relays might originate at either end of the line. An economical design is possible, when only the tone generators and filters which are required are installed at each station. The number of tones which can be used and their place in the frequency spectrum are determined by the sharpness of cut-off in the band-pass filters. Three tones of 3,000, 4,000, and 5,000 cycles were chosen and assigned to the lines, as shown in Figure 2.

The usefulness of this method of carrier relaying depends on whether or not the impulse can be transmitted past the line fault. Tests on lines with grounded conductors showed that, with suitable carrier sets, the impulse could be sent past a ground on one or two wires of the circuit and probably past arcing grounds on all three wires.

Investigation showed that equipment could be obtained wherein both the desired functions of communication and relaying could be combined. Moreover, one set could be coupled to two transmission lines at each terminal, so that one set could be used to serve two lines. It was decided to proceed with a trial installation which would provide communication with Beauharnois and an improvement in the relaying on three lines shown in Figure 2, with the intention that if operation is successful, similar equipment will be installed on the other long lines. The sets and the installation are described in more detail in a later part of this paper.

Auxiliary and Out-of-Step Relays

A schematic diagram of the relay system at one end of the transmission system is shown in Figure 3. A description of the standard relay system for protection of a transmission line is unnecessary. However, the additional relays which are shown in this diagram will be described in the paragraphs hereinafter.

The out-of-step relays are standard "slug" relays of the telephone type, which are equipped with a sealed mercury contact for opening a circuit after a time delay. These operate in the following man-

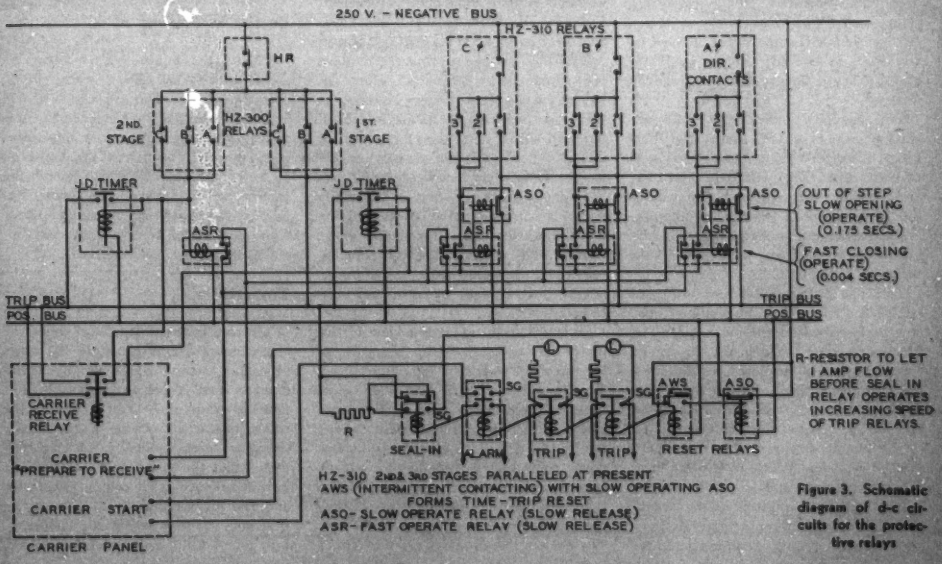

Figure 3. Schematic diagram of d-c circuits for the protective relays

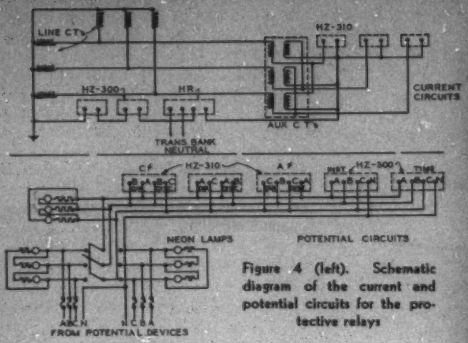

Figure 4 (left). Schematic diagram of the current and potential circuits for the protective relays

Figure 5. Front view of panel showing the protective relays

ner: If the system should become unstable, all three of the second-stage impedance relays will operate during the swing, and open the trip circuit of the first-stage impedance relays. If the system should remain out of step, the second-stage relays would permit tripping ultimately through the contacts of the *JD* timer. However, if the system should swing back, the first-stage impedance relays will reset, followed by the second-stage impedance relays and the type *ASO* relays, provided the *JD* timer has not closed its contacts. If the out-of-step condition progresses or revolves faster than the time setting of the *ASO* relays, the trip circuit will be closed through the contacts of the first-stage impedance relays. The operation of the first-stage relays on faults within the 80 to 90 per cent section of the line is not affected in any way, as the trip circuit would be closed prior to the operation of the *ASO* relays.

The auxiliary relays type *ASR* are similar to the type *ASO*, except that their action is not delayed. Their function is twofold: first, they operate the *JD* timer, and second, they prepare the carrier set for reception of the tone or impulse, if the carrier equipment happens to be in use for transmitting a telephone conversation at the time.

The type *ASO* and *AWS* relays for resetting the trip circuit are similar to the relays described heretofore, and their function is merely to keep the trip-circuit type *SG* relays in the closed position for a predetermined time, during which the carrier transmitter is started and the appropriate relaying tone is transmitted to the remote station. This time delay must be sufficiently long to trip the local breakers properly and to permit the reception of the relaying tone at the far end of the line where the contacts on the timer for the second-stage impedance relays must be by-passed long enough to permit tripping the breakers.

The current and potential circuits for the protective relays are shown in Figure 4, which contains some points of interest. Delta connection of the neon lamps was necessary because they would not always "strike" on the phase-to-neutral voltage of approximately 60 volts. Star-connected current transformers are used as the source for both the phase-to-neutral impedance relays and the phase-to-phase impedance relays. The zig-zag connection of the auxiliary current transformers has some advantages: first, it allows the use of ground relays while maintaining delta equivalent currents in the phase relays, and second, the volt-ampere burden on the main current transformers is less than straight isolating auxiliary transformers.

Figure 5 shows a general view of the power-line protective-relay panels. At the top of the panels are the phase relays. The ground relays are next, and below these are the timing relays. The type *HR* directioned ground-current relays are in the center of the panels farther down. The type *ASO* relays for out-of-step operation are on the right of the type *HR* relay, and the "prepare-to-receive" relays type *ASR* are at the left. The bottom line of relays are the "trip", "carrier start", "alarm," and "seal-in" relays. The neon lamps are without covers. The telephone-type lamps are used for trip-circuit supervision.

Carrier Equipment

The carrier equipment at each terminal consists of the following units: the carrier transmitter which is connected by a carrier frequency transmission cable to the line tuning unit, the coupling capacitor by which carrier is impressed on each line, the line trap which isolates the carrier currents from the power frequency switching equipment and transformers, and the control unit which includes the carrier receivers.

Transmitter

The transmitter is capable of delivering a maximum of approximately 400 watts of carrier energy, which can be modulated at least 90 per cent, into a load of nominal value of 70 ohms. This is the characteristic impedance of the carrier frequency transmission cable employed to transmit the energy to the line tuning unit and thence to the coupling capacitor and the high-voltage line. The carrier frequency range is 145 to 205 kilocycles. Low temperature-drift quartz crystals in

duplicate are employed as the primary source of carrier energy.

The carrier circuits consist essentially of a crystal oscillator followed by a low-power buffer amplifier, a driver amplifier, an intermediate power amplifier, and a final power amplifier. All circuits are tuned with the exception of the buffer amplifier, which is impedance coupled to the driver. The driver may be connected as a master oscillator by a single switching operation. The output circuits are designed to couple to a transmission cable or other nonreactive load of approximately 70 ohms and to pass the sidebands represented by modulating frequencies up to 6,000 cycles per second without serious attenuation.

The power output of the transmitter may be reduced to a minimum of approximately 15 watts. Power reduction is accomplished in three coarse steps corresponding to approximately 165, 50, and 15 watts. The method used consists essentially of inserting resistance in the plate circuit of the final amplifier stage, thus reducing the net plate voltage. The primary reason for thus reducing the power is to minimize interference on other services, since, under normal conditions and for short distances, the full power is not required for telephony. However, the power must be raised to its full value when a signalling tone is to be transmitted, so a contactor is employed to shunt the resistance out when signalling is required.

The audio-frequency system consists of an input amplifier stage, a driver stage, and a push–pull modulator stage. The system was specially designed to give an audio characteristic which is substantially uniform from 100 to 6,000 cycles. The total harmonic distortion with full carrier power and 90 per cent modulation depth is less than five per cent. The carrier noise is more than 45 decibels below 90 per cent modulation.

Included in the transmitter is a changeover relay actuated primarily by the voice-operated devices and the tone signalling circuits. This relay transfers the output circuits from "received" to "transmit", besides controlling the carrier. The carrier transmission is started by applying plate voltage to one of the lower stages. In the "stand-by" condition, all other plate voltages remain on, and the anode currents are reduced by appropriate grid bias voltages. The crystal stage is allowed to oscillate continuously, as crystals on these carrier frequencies are often slow in starting. By the use of suitable shields and filters, any pickup in the associated receiver is avoided.

Control Unit

The control cabinet includes the following units: two carrier receivers, a receiving amplifier containing the voice-operated disabling device, and an amplifier for the calling loudspeaker, a transmitting amplifier containing the voice-operated carrier-control device and calling oscillator, two low-pass filters, two tone generators, two filter amplifiers, and a calling unit containing the hybrid coil, auxiliary relays, and microphone supply.

Each of the carrier receivers consists of a seven-tube unit, designed for the reception of frequencies between 140 and 200 kilocycles, and comprising a tuned radio-frequency amplifier controlled by an amplified automatic volume control circuit. The input circuits to the receivers include two wave traps and an input attenuator, together with a muting relay which blocks the receiver while the transmitter is operating. This relay is controlled by contacts on the antenna changeover relay, in such a way as to close the contacts on the muting relay before the transmission of carrier begins, and thereby eliminate at the receiver output any pickup from the carrier. This pickup is quite appreciable and is due to a large extent to the capacity effects at the antenna changeover relay. The wave traps are incorporated to provide mitigation of adjacent channel interference. The input attenuator provides a coarse adjustment of carrier input level to ensure that the normal incoming carrier will work the *AVC* circuits properly and to assist in overcoming the effects of noise. Since the noise level is relatively high, the receiver is relatively insensitive, requiring a minimum input of 45 millivolts

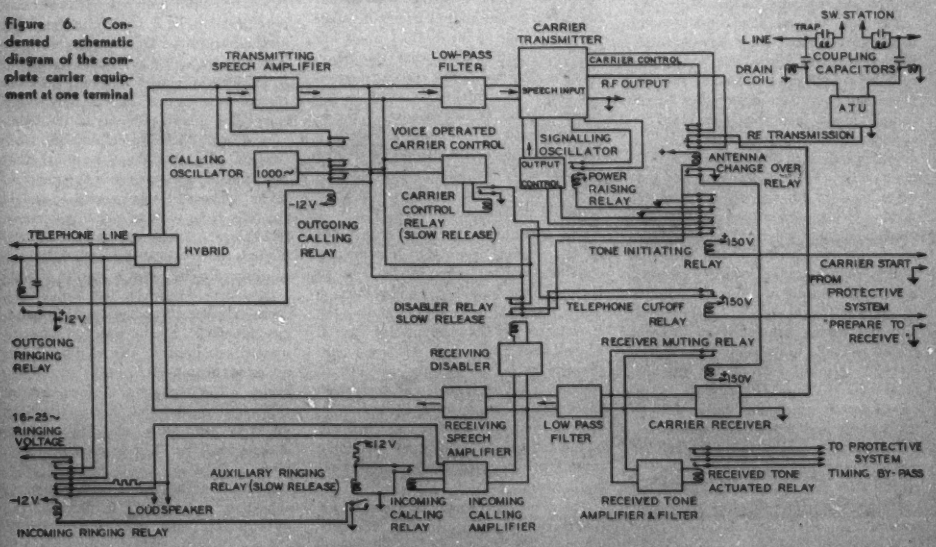

Figure 6. Condensed schematic diagram of the complete carrier equipment at one terminal

Figure 7. Front view of carrier transmitter and control cabinet

Figure 8. Antenna tuning unit and 220-kv coupling capacitor

for 110 milliwatts ouput. The normal input to the receiver may be as much as one or two volts, depending on transmitter power and attenuation between sending and receiving stations.

The receiving amplifier consists of the following: a single-stage speech amplifier to raise and control the level of the received speech prior to feeding the telephone line, a two-stage amplifier for the calling circuits, and a voice-operated disabling device. The output of the calling amplifier is divided two ways, part operating a conventional loudspeaker, and part being rectified for the operation of the various calling and ringing relays. The disabler includes gas-filled rectifier tubes which are triggered by the incoming speech from the radio frequency receiver, causing the closure of a relay which acts to prevent the operation of the voice-operated carrier control if an attempt should be made to transmit while speech is being received. Moreover, the disabler acts to block the passage of received speech which might pass through the hybrid and enter the transmitter. The relay is a slow-release type and remains closed for approximately half a second after cessation of speech, to avoid operation between syllables or short pauses.

The transmitting amplifier is similar to the receiving amplifier and includes the following: a single-stage speech amplifier to raise and control the level of the speech appearing on the telephone line before it enters the transmitter, a voice-operated carrier-control device and a 1000-cycle calling oscillator with amplifier. The carrier control circuit is essentially the same as the disabler which has been described, except that the relay, which is governed by the speech-triggered gas tubes, is arranged to operate the carrier control and changeover relay in the transmitter. The relay actuated by speech is arranged for a releasing time of approximately one quarter second, so as to hold in between syllables and short pauses in the speech.

One of the low-pass filters is connected in the output from the transmitting amplifier, and the other in the input to the receiving amplifier. The purpose of the former is to avoid modulating the transmitter by components of speech above about 2,500 cycles. If these components lie in the vicinity of 3,000 to 5,000 cycles, they would tend to operate the relaying equipment which is responsive to these frequencies. The purpose of the latter is to exclude the signalling tones from the telephone line at the receiving end.

The tone generators are identical for the three frequencies in use, the only difference being in the constants of the oscillating circuit. The oscillator functions at all times, and the amplifier following it is blocked off at all times except when it is required. This blocking is removed when a tone initiating relay on the transmitter is closed by the operation of the 25-cycle protective system.

The filter amplifiers are identical for the three frequencies in use, the only difference being in the elements of the band-pass filters which are employed. Each consists of a two stage amplifier that is bridged on the output of the radio receiver. The first stage serves to isolate the filter from the line and to allow control of level. The second stage is a power pentode whose output is rectified, and the resultant direct current is used to actuate a contactor. Between the two stages, there is inserted a single section band-pass filter with a band width of approximately 400 cycles. The mid-band frequencies are 3,000, 4,000, and 5,000 cycles. The contactor is energized by the rectified output of the amplifier following the filter, and its contacts operate into the 25-cycle protective system.

The calling unit is a combination of subsidiary apparatus. It includes the hybrid coil and balancing network

which couple between the two-wire telephone line and the four-wire communication channel represented by the transmitter input and the receiver output. A small rectifier of the dry-disk type with a filtering system is the supply for the local hand-set. The unit also carries sundry relays associated with the calling system. The low-frequency ringing current on the telephone line is converted into 1,000-cycle current which modulates the carrier. At the receiving end, the 1,000-cycle current operates both the loudspeaker and the relay which impresses the low-frequency ringing current on the called telephone line. The loudspeaker is cut off normally, being in operation only when a call is coming in.

Line Tuning Unit

This unit is mounted out of doors adjacent to the coupling capacitors. It contains the necessary coupling devices to transfer energy from the carrier frequency transmission cable to the 25 cycle high-voltage lines. Also it contains the loading inductances to tune out the reactance of the coupling capacitors. Two separate coupling and loading systems are contained in the unit, so that energy can be fed into two lines in any proportion. As the carrier frequencies are relatively high, the various coils are wound of stranded high-frequency cable. Air core coupling transformers are employed.

Operation

A condensed schematic diagram of the complete system for one terminal is shown in Figure 6.

(*a*) Signalling Tone Transmission

When a fault occurs near one end of the line which is 300 miles long, an impedance relay at the terminal near the fault closes its contact instantaneously. This operation trips the breaker at the near end, and at the same time starts the transmission of carrier modulated at 3,000 cycles by energizing the appropriate auxiliary tone-initiating relay which takes complete control of the carrier equipment at that terminal. This relay actuates the antenna changeover relay, which, in turn, mutes the receiver and starts both the carrier and the 3,000-cycle relaying or signalling oscillator. At the same time, the power-raising relay is actuated to increase the power of the transmitter to its full value. The transmitter then emits carrier, modulated only by the 3,000-cycle tone, for as long as the auxiliary tone-initiating relay is kept energized.

If the transmitter be in use at the time when a tone must be transmitted from the same terminal, the antenna changeover relay will be in the "transmit" position already, because of the action of the voice-operated carrier-control device. In this case, the tone-initiating relay overrides the talker, and the power is raised. The complete relaying operation will be as fast, or a little faster, than usual, because the carrier had been turned on previously. Moreover, the speech line is short-circuited to de-energize the voice-operated carrier control, and to avoid using up any of the modulation capability of the transmitter by the speech which is of secondary importance at the moment. As soon as the tone-initiating relay is de-energized, the system is restored to normal, and the remainder of the talker's conversation will be transmitted as usual, the power dropping back to its original level.

If two or three relaying tones are required, they can be modulated simultaneously at the expense of a small reduction in the modulation depth of each. This reduction is not so great as to impair the operation of the relays at the distant end.

(*b*) Signalling Tone Reception

The tones, demodulated from the carrier, appear at the output of the carrier receiver and enter the received tone amplifiers and filters. The low-pass filter blocks them from the receiving speech amplifier and prevents them from being heard by the listener if a conversation is in progress. The band-pass filters in the amplifiers separate the wanted tone from the others, or from speech, and the proper relay is actuated by the received tone. The contacts of this relay put a by-pass across the contacts of the timer on the second impedance range, making this range almost instantaneous.

If the equipment happens to be in use for transmission of one part of a telephone conversation, and a relaying tone is to be received, dependence is placed on the telephone cut-off relay, which is actuated by the second range impedance relays at the same time as the *JD* timer is started. This operation occurs at the same time as the relaying tone is started at the distant end. The telephone cut-off relay opens the circuit to the antenna changeover relay even though it has been closed by the talker. This relay is forced to go to the "receive" position, and the receiver is unblocked. The equipment is thus prepared to receive the tone at the same time as the carrier modulated by the tone arrives.

If the second range impedance relays energize the telephone cut-off relay at the same time as the tone-initiating relay is energized by the trip relay, then the tone-initiating relay overrides all else and the sequence proceeds correctly.

The time which is lost between energizing the tone-initiating relay at the end of the line nearer to the fault and the closure of the relay by the received tone at the distant end is in the order of 0.9 of a cycle on 25 cycles per second, if the equipment at both ends is in the stand-by condition. If the carrier equipment is in use for telephony, and the transmission is in the same direction as the relaying tone must be sent, the lost time is somewhat less, being about 0.5 of a cycle on 25 cycles per second. If the equipment is in use for telephony and the transmission is in the opposite direction to that which is required for the relaying tone, the total time lost is in the order of 1.5 cycles on 25 cycles per second. This is the slowest case because the system must be prepared to receive the tone as described previously.

A general view of the radio-frequency equipment is shown in Figure 7. At this station, these cabinets are 2,400 feet from the antenna tuning unit and about 2,000 feet from the panels on which are mounted the protective relays. The antenna tuning unit and a coupling capacitor are shown in Figure 8.

Conclusions

This carrier relay scheme which uses a tone as a transfer trip impulse, as described above, has several advantages. Standard protection relays of any type may be used. Only one carrier set is required at each station, coupled to as many lines as need this protection. The number of relaying tones or channels is limited only by selectivity of the band-pass filters. The carrier system operates as a telephone circuit normally, and only as a carrier relaying feature for an interval of one second for every line fault. A failure of the carrier increases the clearing time only for those faults which are in the end sections.

Reference

1. The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario—II, A. H. Frampton, E. M. Wood: AIEE Transactions, volume 60, 1941, pages 1215-21.

Temperature Limits and Measurements for Rating of D-C Machines

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Synopsis: Existing industrial practice for determining the temperature rise of d-c machines is based on measurements with thermometers, placed on exposed or accessible surfaces of the machine. Tests using resistance measurements with improvements in technique have disclosed the existence of considerably higher internal temperatures than those indicated by thermometers, especially for short-time rated machines. Experience has indicated, nevertheless, that such machines have entirely satisfactory service records.

Greater accuracy and consistency are possible with the resistance method, with proper measurement techniques, and it affords a truer indication of winding temperatures. This paper, therefore, suggests that the resistance method should be more generally used and should ultimately be recognized in the Standards as is now the case for railway motors. With this in view, detailed recommendations for resistance-measurement technique are presented.

Correlation of the temperature rises determined by the resistance method with those measured by the thermometer method is necessary if resistance methods are to supplant the now standard thermometer methods. This paper shows the relation existing between temperature rises measured by thermometer and those measured by resistance on variously ventilated and insulated machines.

Values for temperature limits measured by resistance for continuous and short-time rated class-*A* and class-*B* insulated d-c machines are presented. These are consistent with the recently published AIEE Standard 14 "Report on General Principles for Rating of Electrical Apparatus for Short-time, Intermitteut or Varying Duty." The information presented in this paper is intended to apply primarily to low-voltage (approximately 600 volts maximum) d-c machines with form-wound armature coils and conventional types of field coils.

Temperature Measurements

STANDARDS for rating d-c machines provide temperature limitations for the protection of winding insulation. Although there are three recognized methods of temperature measurement, namely,

1. Thermometer method
2. Resistance method
3. Embedded-detector method

the present AIEE practice is based on the thermometer method.

The embedded-detector method is used to determine interior temperatures at designated locations within windings. It is also used in small motor windings, with thermocouples, in specified locations inaccessible to mercury or alcohol thermometers.

The thermometer method is perhaps the easiest to apply, at least for open-type machines, and requires the least amount of equipment. Although the thermometer method has been used for many years with varying degrees of success, it indicates a temperature that is generally less than the internal temperature of the winding being measured. The thermometer may register a temperature very much less than the average copper temperature, depending on the size of motor, length of heat run, ventilation, internal temperature, and insulation. If within a motor one winding is 20 degrees centigrade hotter than the other winding, the thermometer on the cooler winding may actually register a temperature higher than the average copper temperature of that winding. In practically all cases, however, and especially for short-time ratings, the thermometer on the hottest winding will register a temperature less than the average copper temperature of that winding.

The thermometer method has met the needs of industry for many years, and is still adequate for practical purposes. However, it is difficult to obtain consistent results by the thermometer method, because of variations in surface conditions, thermometer locations, and ventilation. Quite often heat runs on duplicate machines or on the same machine

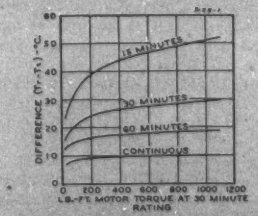

Figure 1. Temperature difference of resistance rise minus thermometer rise versus size of motor for various lengths of heat runs of class-*A*-insulated totally enclosed motors

T_r = Temperature rise by resistance, degrees centigrade

T_t = Temperature rise by thermometer, degrees centigrade

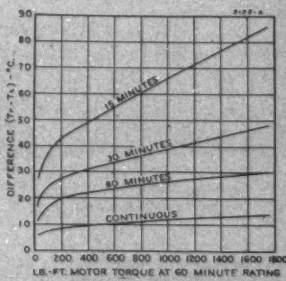

Figure 2. Temperature difference of resistance rise minus thermometer rise versus size of motor for various lengths of heat runs of class-*B*-insulated totally enclosed motors

T_r = Temperature rise by resistance, degrees centigrade

T_t = Temperature rise by thermometer, degrees centigrade

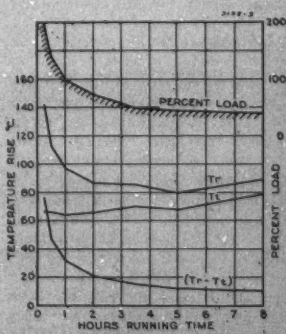

Figure 3. Temperature rise versus length of heat run on a totally enclosed motor

Shaded curve shows per cent load applied for each heat run

T_r = Temperature rise by resistance, degrees centigrade

T_t = Temperature rise by thermometer, degrees centigrade

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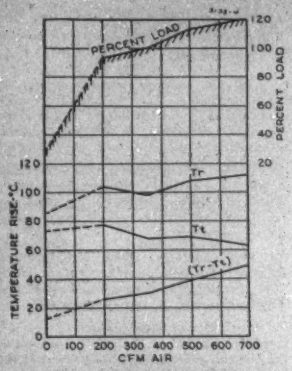

Figure 4. Temperature rise versus volume of ventilating air for continuous heat runs on a blown motor

Shaded curve shows per cent load applied for each heat run. Zero air heat run taken on totally enclosed motor

T_r = Temperature rise by resistance, degrees centigrade

T_t = Temperature rise by thermometer, degrees centigrade

will not check previous thermometer tests with a reasonable degree of accuracy. Another shortcoming of the thermometer method is that it does not indicate the internal temperature of the winding.

The resistance method gives the average temperature of the copper in the winding being measured. This method requires more equipment than the thermometer method, but, when it is applied with the proper technique, more accurate and consistent results may be expected. The main advantage of the resistance method is that it indicates the average copper temperature within the winding, which is generally closer to the hot-spot temperature in any part of the winding than would be indicated by the thermometer method.

The rise by resistance is, in general, higher than the rise by thermometer, and the former should, therefore, be a better indication of the temperature which limits insulation life.

Temperature Ratings

For many years it has been the accepted practice to limit the temperature rise on d-c machines to predetermined values, depending on the class of insulation, ambient temperature, and degree of enclosure. The allowable temperature rises were derived from hot-spot temperatures, which were established as being the maximum that a particular class of insulation could withstand continuously and give satisfactory winding life. AIEE Standards 5 (D-C Rotating Machines, Generators and Motors) and 45 (Electrical Installations on Shipboard) and American Standard *C50* (Rotating Electrical Machinery) currently specify that the temperature rise be measured by thermometer, and that the limiting observable rises on insulated windings for a 40-degree-centigrade ambient temperature be as follows:

	Degrees Centigrade	
	Class-A Insulation	Class-B Insulation
Totally enclosed	55	75
Open and semienclosed	50	70

General-purpose machines with a service factor of 1.15 are rated 40 degrees centigrade rise for class-*A* insulation. Although the foregoing temperature-rise limits were established primarily for continuous-rated machines, they have been applied without change or allowance to short-time-rated motors. The most commonly used short-time ratings are 30 minutes and 60 minutes, but 15-minute ratings are also used. The majority of crane motors carry a 30-minute rating, although they may be used in continuously repeated duty-cycle service. Marine-type motors for deck machinery are rated on a short-time basis of 30 or 60 minutes, generally on the former of these two bases. Since the majority of crane motors, and practically all marine deck motors, are totally enclosed, they have been built with short-time horsepower ratings limited by temperature rises of 55 degrees centigrade for class-*A* insulation and 75 degrees centigrade for class-*B* insulation, as determined by the thermometer method of measuring temperature. Many thousands of such motors have been in service for years and have given satisfactory performance. The satisfactory life of the insulation in such short-time-rated motors is due as much to the careful applications of the motors as to the temperature rise on which their rating is based. These motors, although rated on a short-time basis, are generally applied on a duty-cycle basis. In applying such motors, it is common practice to calculate the root-mean-square load, or the average watts loss of the cycle, to make sure that the motor has sufficient thermal capacity, assuming that the duty cycle is to be repeated continuously or for a specified period, so that it can be operated without the allowable temperature rise being exceeded.

Thus it is seen that a short-time horsepower rating is merely a "gauge" which gives the user a conception of the physical size and torque capacity of the motor, but which conveys nothing concerning the continuous thermal capacity of the motor. Although the temperature rise measured by thermometer at the end of the short-time heat run is equal to or less than the allowable rise of 55 degrees centigrade for class-*A* or 75 degrees centigrade for class-*B* insulation, the rise indicated by resistance measurements is greater than these values.

In a previous paper[4] data were presented to show the difference between temperature rises of d-c machines when determined by the thermometer method as compared with those determined by the resistance method. These data were taken from tests on class-*B*-insulated totally enclosed motors. The present paper presents additional data on differences between rise by thermometer and rise by resistance. Information is given on totally enclosed, self-ventilated, and blown motors, with class-*A* and class-*B* insulation, and on various sizes of motors.

The amount by which the rise measured by resistance exceeds the rise measured by thermometer for various time ratings for various sizes of totally enclosed motors is shown in Figures 1 and 2. The temperature-rise differential (resistance rise–thermometer rise) is shown plotted as a

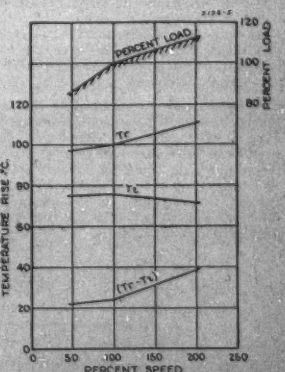

Figure 5. Temperature rise versus speed for continuous heat runs on a self-ventilated motor

Shaded curve shows per cent load applied for each heat run

T_r = Temperature rise by resistance, degrees centigrade

T_t = Temperature rise by thermometer, degrees centigrade

function of the 30-minute rated torque for a line of class-*A* motors and as a function of the 60-minute rated torque for a line of class-*B* insulated motors. These curves are plotted in this manner to show the general relation that exists between the various time ratings for a given size of motor, as well as the relation for a given time rating for various sizes of motors, the torque rating being an indication of the physical size of the motor. All heat runs from which the curves of Figure 1 were derived were made to give approximately 55 degrees centigrade rise by thermometer on the hottest winding. Likewise the heat runs for Figure 2 were made to give approximately 75 degrees centigrade rise by thermometer. In practically all cases, the armature was the hottest winding. Hence, the curves of Figures 1 and 2 are all based on armature temperatures. All thermometer measurements were made with mercury thermometers.

From these curves, general relations with respect to temperature differential (resistance rise–thermometer rise) can be expressed as follows:

1. For a given size of motor and thermometer rise, the shorter the time rating the greater the temperature differential. The reason for this is that, the ratio "watt-hours absorbed to watt-hours dissipated" is greater, the shorter the time. The watt-hours absorbed by the windings raise the copper temperature (resistance rise) while those dissipated raise the surface temperature (thermometer rise).

2. For a given time rating and thermometer rise, the larger the machine, the greater the temperature differential. The reason for this is that, the larger the machine, the greater the ratio of watt-hours absorbed to watt-hours dissipated.

3. For a given size of machine and time rating, the higher the thermometer rise, the greater the temperature differential. The reason for this is that, for a given insulation, more watts per square inch are required to produce a higher thermometer rise on the surface of the insulation, and the greater the watts per square inch, the greater the temperature differential.

Figure 3 shows temperature rises both by the thermometer and by resistance obtained from a series of heat runs made on one totally enclosed motor. The shaded curve shows the value of load that was applied for each heat run, expressed as a percentage of the one-hour load.

Figure 4 shows the effect of ventilating air on the differential between resistance rise and thermometer rise for a blown continuous-rated constant-speed motor. Figure 5 shows a similar effect on a self-ventilated motor on which heat runs were taken at various speeds obtained by holding constant field strength and varying the armature voltage. From Figures 4 and 5, it can be seen that, for a given size of motor, the more the ventilating air, the greater will be the difference between the rise by resistance and the rise by thermometer for continuous heat runs with approximately the same thermometer rise.

Figures 1 to 5, inclusive, are based on an average of many tests and are intended to show some of the various factors that cause a variation in the difference between resistance and thermometer rises.

From the foregoing it can be seen that, although it has been standard accepted practice to rate machines 55 degrees centigrade (class *A*) or 75 degrees centigrade (class *B*) rise by thermometer, the rise by resistance exceeds that by thermometer even on totally enclosed continuous heat runs. AIEE Standard 1 now recognizes a temperature differential of ten degrees centigrade between resistance and thermometer measurements for continuous apparatus. This is very close to that obtained from tests on totally enclosed motors, as shown in Figures 1, 2, and 3. However, especially for short-time rated motors, the resistance rise often will exceed the thermometer rise by an amount considerably greater than ten degrees centigrade.

The question that immediately arises is how to reconcile the higher internal temperatures disclosed by this investigation and the satisfactory service experience recorded with the generally recognized temperature-rise limits of 60 degrees centigrade by resistance for class *A* and 80 degrees centigrade for class *B*, given in AIEE Standard 1 and various American Standard and International Electrotechnical Commission Standards. However, the temperature-rise value desirable for any given case depends on many factors besides the insulating materials themselves. The ultimate choice is largely a matter of economics, depending on the relative importance of weight, size, reliability, cost, and life expectancy.

For example, it is well known that 120 degrees centigrade rise is allowed for class-*B* insulated railway motors (with 25 degrees centigrade ambient temperature assumed), whereas only 60 degrees centigrade rise by resistance is normally allowed for the high-voltage armature windings of large alternators with class-*B* insulation (on the basis of 40 degrees centigrade ambient temperature). In the particular case of low-voltage d-c machines, with form-wound armature coils and the usual type of field structure that are alone considered in this paper, the following factors are favorable to the use of higher internal temperatures:

1. The low voltages (approximately 600 volts maximum), the mechanical requirements, and the form-wound construction necessarily result in extremely low dielectric stresses.

2. The low voltage and corresponding small insulation thickness considerably reduce difficulty from varnish-solvent expulsion and coil swelling that limit high-voltage coil temperatures.

3. The relatively short armature-core lengths customary for d-c machines minimize the difficulties from thermal expansion, which are serious in large a-c machines.

4. The type of construction of the d-c rotating armature, including the commutator and the end-binding bands, restricts the exposure of the windings, resulting in a relatively greater difference between internal and external winding temperatures than in the case for induction and synchronous machines. At the same time, the parts of the insulation subjected to the higher temperatures are less exposed to oxidation, moisture, and atmospheric impurities.

Conclusions

In view of the desirability of internal rather than external temperatures as a basis of rating, and the greater accuracy and consistency that may be obtained, it is recommended that improved methods of temperature measurement by resistance be included in the AIEE test code for d-c machines and considered for later adoption as a basis of rating in the Standards. For the latter purpose, the following values of limiting observable temperature rises for both fields and armature windings of d-c machines determined by the resistance method are suggested for consideration:

Limits of Observable Temperature Rises Determined by the Resistance Method for 40 Degrees Centigrade Ambient (Degrees Centigrade)

Class of Insulation	Continuous	One Hour	30 Minutes	15 Minutes
A	65	75	85	95
B	100	110	125	140

1. The values agree with AIEE Standard 14, Table II, short-time ratings, except for the 15-minute rating.

2. The values for class-*B* insulation agree with AIEE Standard 1 Table V, preferred values of standard observable temperature rise for short-time or other special ratings.

3. The values are somewhat more conservative than railway motor values AIEE Standard 11, Table II.

The suggested values are intended to apply to low-voltage (approximately 600 volts maximum,) d-c machines with form-wound armatures and conventional

field coils. The values are not intended to apply to other classes of machines where the type of construction and nature of application differ.

Satisfactory experience has been obtained with the suggested values of rise by resistance in machines that meet present thermometer standards. For continuous-rated highly ventilated machines, these values will limit the rise by resistance to a value less than is permissible with the present thermometer standards.

Appendix I. Resistance Measurements

In order to promote the general acceptance of the resistance method of determining temperature rises, and thereby further improve the technique of this method, the following description of a method for determining temperature rise by resistance is offered.

The temperature by resistance method gives the average temperature of the winding being measured. This method consists of comparing the resistance at the end of a heat run (hot resistance) with the resistance at a known temperature (cold resistance). The temperature rise at the end of a heat run is determined by the following formula, which applies to copper windings only:

$$T - t_a = \frac{R_T - r_t}{r_t}(234.5 + t) + t - t_a \qquad (1)$$

in which

R_T = resistance in ohms of the winding at temperature T degrees centigrade (this will be the hot resistance measured at an unknown temperature T at the end of a heat run)

r_t = resistance in ohms of the winding at temperature t degrees centigrade (this will be the cold resistance measured at a known temperature t)

t_a = the mean ambient air temperature in degrees centigrade during the last quarter of the duration of the test

$T - t_a$ = the temperature rise in degrees centigrade of the winding above the ambient temperature

A convenient method for determining temperature rise by resistance is as follows:

1. Plot the relation of per cent change in resistance as abscissa against the temperature in degrees centigrade as ordinate. This straight-line relationship is shown in Figure 6 in which a reference temperature of 25 degrees centigrade has been chosen. It is recommended that the scale for the per cent change in resistance be chosen large enough so that it can be read accurately to the first decimal point.

2. Measure the cold resistance of each winding in the motor, and record the temperature of the windings as determined by placing thermometers thereon. Correct the cold resistance from the measured temperature (thermometers on windings) to 25 degrees centigrade. A convenient table for this correction is Table I.

3. Measure the hot resistance at the end of the heat run, and from the percentage increase in resistance $100(R - r_{25})/r_{25}$ read from Figure 6 the corresponding temperature. Subtract the ambient or cooling-air temperature t_a to obtain the temperature rise.

4. To obtain the temperature rise at the instant of shutdown (at time the power was cut off), record the time at which each hot resistance was taken, the time being measured from the instant of shutdown. Take a series of hot-resistance readings at approximately two-minute intervals for approximately 20 minutes. These points can then be plotted as temperature rise (by resistance) as ordinates and time as abscissae. A curve drawn through these points and extrapolated back to zero time will give the temperature rise at the instant of shutdown. A typical cooling curve is shown in Figure 7.

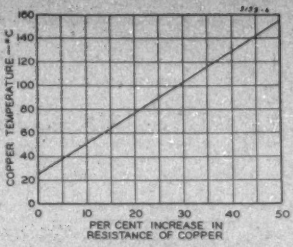

Figure 6. Temperature versus per cent increase in resistance of copper

In some cases, especially at the end of short-time heat runs, the slope of the cooling curve changes rapidly, and there is a large change in temperature during the first few minutes after power is off. It is therefore important to bring the machine to a standstill and take the first reading on each winding as quickly as possible. The cooling curve for the hottest winding generally has the greatest slope, and, since it is the limiting winding in determining the rating of the machine, care should be exercised in determining accurately the zero-time temperature rise on this winding.

There are two methods in common use for determining resistance

(a). The drop of potential, or voltmeter–ammeter method. This method is used to best advantage on resistance greater than five ohms.

(b). The comparison method in which the unknown resistance is compared with a known resistance by some suitable bridge. For measuring resistances less than five ohms, it is recommended that a Kelvin double bridge be used.

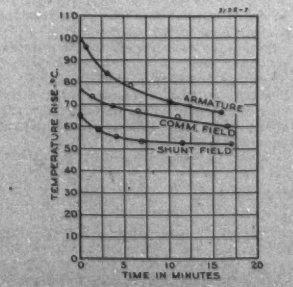

Figure 7. Typical cooling curves determined by the resistance method

Time is measured from instant of power off, taken after a continuous blown heat run

The success of measuring resistance by either the voltmeter–ammeter method or the bridge method depends to a great extent on the wiring and connections between the instruments or bridge and the machine windings being measured. Since for most d-c motors there are at least three elements to be measured—armature, commutating field, and main field—it is important that the wiring of the test table be so arranged that readings on all windings may be made at the end of a heat run in the minimum amount of time and by using only one set of instruments and/or one bridge. To accomplish this in the minimum time and with the least confusion, it is recommended that switches be used in the voltage circuits.

A convenient arrangement of test-table wiring for measuring cold and hot resistances is shown in Figure 8. Such an arrangement can be installed on individual test tables or on a portable resistance table which can be moved to any test stand.

Figure 8 shows the test-table wiring, the motor windings, and a Kelvin double bridge. The bridge is connected to the wiring by an ammeter jack and a voltmeter jack and can, therefore, be replaced readily by an ammeter and a voltmeter. In this diagram are included two extra sets of voltage leads, in addition to the three connected to the field windings which may be used for additional field windings, such as in a motor–generator set. The forks are used for measuring armature resistance. When field resistances are being measured, current is circulated through all field windings. By closing the proper switches, the voltage leads for each winding can be connected to the bridge individually.

Table I

Degrees Centigrade Temperature of Cold Resistance	K	Degrees Centigrade Temperature of Cold Resistance	K
15	1.040	26	0.996
16	1.036	27	0.992
17	1.032	28	0.989
18	1.028	29	0.985
19	1.024	30	0.981
20	1.020	31	0.977
21	1.016	32	0.974
22	1.012	33	0.970
23	1.008	34	0.967
24	1.004	35	0.963
25	1.000		

Multiply cold resistance by K to obtain resistance at 25 degrees centigrade.

The following precautions should be observed in wiring a table, as shown in Figure 8, and in taking resistance measurements to determine temperature rise. Although some of the precautions are not necessary for the voltmeter–ammeter method, they are necessary for the double-bridge method.

1. Each individual voltage lead between the bridge and the field windings should have approximately the same resistance as the other lead in the same pair and should be of relatively low resistance, preferably less than 0.1 ohm per lead.

2. All connections in the voltage leads must be clean and tight. All permanent connections should be soldered.

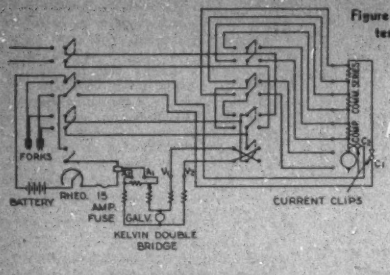

Figure 8. Schematic wiring diagram of test table for measuring resistance

3. All switches must be kept clean and free of dust or corrosion. The swivel connection on all switches between the handle and the base should be shunted with flexible copper shunts, one end of which is soldered to the switch blade and the other end to the connecting wire.

4. Pigtails should be soldered to the field-coil leads, so that the voltage leads can be bolted tightly to the pigtail and not connected at the joint where one field-coil cable connects to another cable.

5. For measuring armature resistance, the forks should be used. In each fork are a current and voltage lead soldered to brass pins ($^1/_2$ inch diameter), insulated from each other and held rigidly in the handle so that pressure can be applied without moving the pins. The forks should be applied to the ends of two commutator segments, securing the maximum span of segments that can be obtained between two adjacent brushholders. The armature should be so positioned that the brushes will not short-circuit armature coils between the span of the forks. The forks should be pressed firmly against the segments so as to break through any oxide film and make good contact with the copper.

6. Cold and hot resistances should be measured under as identical conditions as possible. For the armature, the bars used for determining cold resistance should be marked, and the same pair should be used in measuring hot resistance. In measuring the resistance of field coils, the voltage leads should be connected in such a manner that it will not be necessary to use the reversing switch after cold resistance is taken. The voltage leads should not be removed or changed between the times of taking cold and hot resistance. The current clips should be placed in the same relative position for both cold and hot resistance—this is very important, as will be explained later.

7. In order that errors in reading the double bridge may be reduced to a minimum, the lowest multiplying factor (see Appendix II) with which the bridge can be balanced should be employed. The measurement is independent of the current, but, the higher the value of current within the current capacity of the bridge, the greater will be the sensitivity of the bridge and, therefore, the accuracy of the readings.

8. Cold resistance should not be taken until all windings are within three degrees centigrade of room temperature.

9. As soon as power is cut off at the end of the heat run, the machine should be stopped as quickly as possible and all voltmeters disconnected, making certain that there are no paths in parallel with the windings to be measured.

10. The resistance of the current path between A_1 and the point where the current clip C_1 (Figure 8) connects to the series cable should be relatively low and of the same value for cold and hot resistance. The reason for this is explained as follows:

Refer to Figure 9 which shows the schematic connections of the Kelvin double bridge connected to an unknown resistance r_x.

The connection between A_1 and the point where V_1 lead is connected to r_x will be referred to as the d link. In Figure 9 the resistance of d may be zero or infinity, and as long as

$$(r_1+r_{v1})/r_3=(a+r_{v1})/b$$

then

$$r_x/r=(r_1+r_{v1})/r_3$$

where a, b, r_1, and r_3 are the resistances of the ratio arms of the bridge and r_{v1} and r_{v2} are the voltage lead resistances. For a ratio of 0.1, assume $r_1=100$, $r_3=1{,}000$, $a=100$, and $b=1{,}000$. When r_{v1} and r_{v2} are zero, then r_x (unknown) $=0.1r$ (standard). Assume $r_x=0.001$, and each voltage lead r_{v1} and r_{v2} to have one ohm resistance, then an error of one per cent will be introduced, because the standard resistance will have to be adjusted to 0.001 (1000/101) = 0.0099 in order to balance the bridge—that is, zero amperes through the galvanometer. Even in this case, as long as the ratio $(r_1+r_{v1})/r_3=(a+r_{v1})/b$ exactly, then the resistance of the d link, theoretically, has no effect.

Practically, it is not possible to maintain an exact ratio of $(r_1+r_{v1})/r_3=(a+r_{v1})/b$. Therefore, any resistance in the d link will introduce an error. The magnitude of this error will depend on the difference in ratios of the bridge arms, including leads, and the value of the d resistance.

When the bridge is balanced:

$$\frac{r_x}{r}=\frac{r_1+r_{v1}}{r_3}+\frac{d}{r}\left(\frac{b}{a+r_{v1}+b+d}\right)\times\left(\frac{r_1+r_{v2}}{r_3}-\frac{a+r_{v1}}{b}\right) \quad (2)$$

In comparing hot to cold resistance to determine temperature rise, approximately the same per cent error would be obtained in the hot resistance as in the cold resistance, thereby minimizing the error in temperature rise, provided that the resistances of the ratio arms, leads, and connections do not change between times of taking hot and cold resistance, and the d link resistance changes in proportion to the standard resistance r.

Since small differences in resistance occur in opening and closing switches, in contact joints, and with temperature change of wires, and the d link resistance does not change in proportion to the standard resistance, good practice dictates that the d link should have relatively low resistance, and the two voltage leads should have approximately the same resistance.

From Figure 8 it can be seen that when the resistance of the compensating field is measured, the commutating and series fields and connecting wires are in the d link. This same arrangement should be kept for both cold and hot resistance. Therefore, the current clips must be placed in the same relative position for both cold and hot resistance. For all practical purposes, the addition of this amount of resistance as compared to the winding being measured should introduce little or no measurable error in determining temperature rise, provided that the same relative connections are maintained for both hot- and cold-resistance measurements. The table wiring should be arranged so that it is not possible to connect the battery and rheostat into the d link.

The possible magnitude of error in resistance measurement caused by resistances in the d link and in the voltage leads is discussed in Appendix II.

The discussion in Appendix II is offered to point out the possibility of error in resistance measurement, and each person employing the double bridge will have to determine from actual experience and checking what refinements are necessary to give reasonably accurate results. If too many refinements are attempted, then the task of measuring resistance on heat runs becomes tedious, and the expense and trouble of such refinements may prove unwarranted. It must not be assumed mistakenly that a small amount of resistance in one of the voltage leads makes little or no difference, as is the case when using the voltmeter–ammeter method. Where a voltmeter may have a resistance of 1,000 ohms, 0.1 ohm inserted in one of the leads would give approximately 0.01 per cent error. The same value inserted in one of the voltage leads of the Kelvin double bridge may produce a considerable error, depending on the value of the unknown and the d link resistances.

The circuits shown in Figures 8 and 9 have been in use in one testing department for a number of years in determining temperature rise by resistance and have given reliable results. If such circuits are installed properly and operated with care, reliable results may be expected.

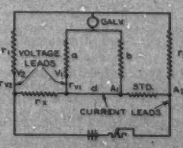

Figure 9. Schematic diagram of Kelvin double bridge

Appendix II. Kelvin Double Bridge

In the double bridge there are a number of adjustments provided in the ratio arms r_1, r_2, a, and b, in order to measure a large range of unknown resistances. For each adjustment $r_1=a$, $r_2=b$, and $r_1/r_2=a/b$. Although in portable forms of the Kelvin bridge $r_1=a$ and $r_2=b$ in most cases, it is not essential that this be so but only that the ratios be equal. The ratio of r_1/r_2 is the multiplying factor which, when applied to the value of observed resistance on the standard, r_s, gives the value of unknown resistance r_x.

For the purpose of discussion, it is assumed that the double bridge, Figure 9, has three multiplying factors to cover the range of 0.0001 ohm to 1.0 ohm resistance of r_x. It is also assumed that the various resistance arms within the bridge have the following values for each of the three multiplying factors:

Multiplying Factor	Resistance in Ohms		Range of Unknown (r_x) in Ohms
	r_1 and a	r_2 and b	
0.1	100	1,000	0.0001 to 0.01
1.0	500	500	0.001 to 0.1
10.0	1,000	100	0.01 to 1.0

The connecting wires between the bridge and the unknown resistance r_x (Figure 9) will introduce an error in the resistance reading. The magnitude of this error depends on the following factors:

(*a*). Resistance of the voltage leads r_{v1} and r_{v2}.

(*b*). Difference between the resistances of the two voltage leads $(r_{v1}-r_{v2})$.

(*c*). Resistance d introduced in the d link.

Two possible causes of error may be considered.

Case I where $d=0$. From equation 2 $r_x=r(r_1+r_{v1}/r_2)$. In this case an error will be introduced by the resistance of the voltage lead r_{v1} which will change the ratio of r_1/r_2 to $(r_1+r_{v1})/r_2$. Therefore, low-resistance voltage leads should be used, and it is preferable that each lead be less than 0.1 ohm. With a multiplying factor of 0.1 and $r_{v1}=0.1$ ohm, the ratio becomes 100.1/1,000 which gives an error of 0.1 per cent, a value that may be considered negligible. The resistance of the V_1 voltage lead r_{v1} will have no effect on the results so long as d is zero, a condition that may never be realized in actual practice.

Case II where $d>0$ and r_{v1} or $r_{v2}\geq 0.1$ ohm. In this case a change in ratio of the first term on the right-hand side of equation 2 due to r_{v2} can be neglected, because the error will be 0.1 per cent or less, although the second term becomes significant. The error caused by the resistances of the voltage leads and the d link is directly proportional to the d-link resistance and to the difference $(r_{v1}-r_{v2})$ in resistance between the two voltage leads. Therefore, voltage leads of approximately equal resistance should be used as well as a low d-link resistance to minimize the error.

The following general relations apply when there is a difference in the voltage-lead resistance, $r_{v1}\neq r_{v1}$ and $d>0$.

1. For multiplying factors of 0.1 and 10:

Approximate per cent error

$$=0.091(r_{v1}-r_{v2})d/r_x$$

2. For a multiplying factor of 1.0:

Approximate per cent error

$$=0.1(r_{v1}-r_{v2})d/r_x$$

When $r_{v1}>r_{v2}$, the bridge will indicate a value greater than r_x.

When $r_{v1}<r_{v2}$ the bridge will indicate a value less than r_x.

From relations 1 and 2 it can be seen that, the lower the unknown resistance, the greater is the probability of error due to poor wiring and connections. These relations apply only to a limited range of resistance of $(r_{v1}-r_{v2})$ and d. They are, however, approximately correct for values greater than should be permitted in actual practice.

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A New Simple Calculator of Load Flow in A-C Networks

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LOAD-FLOW analysis in a-c networks is increasing in importance because of the greater use of loop circuits in transmission and distribution systems to obtain the advantages of network operation.

To make the best use of materials and man power and to keep system investment at a minimum require careful system planning in advance of working up the details of design. If a simple device is made available to engineers responsible for this system-planning work which will enable them to make more complete analysis of system load flow, voltages, losses, reactive requirements, and so forth, in less time than heretofore possible by analytical solutions, it should aid materially in improving the over-all effectiveness and efficiency of the engineers and the systems they design.

A-c boards, network analyzers, or calculators have been developed to a high degree of perfection and are used extensively by the larger operating companies for major problems involving system interconnections and extensive changes or additions. These boards are useful in many ways, and the only objection to them is that they are relatively large and expensive, and for economic reasons they are not available to the majority of engineers except at times when the larger studies are involved. Every power system has many problems arising from day to day which could be answered better and more completely in less time if there was a simple calculator at hand.

It is the purpose of this paper to set forth certain broad principles which form the basis for the design of entirely new and simpler types of calculators for load-flow analysis of a-c networks. Calculators based on these principles may prove to be the answer to system-planning engineers' requirements for small inexpensive units which will be on hand to solve these problems as they arise. The description of one particular form of calculator is given to illustrate the application of these principles to a specific and practical design. Briefly, this calculator consists of a multitap voltage transformer, a few multitap resistors, a measuring instrument which is similar to a three-phase, three-wire electrodynamometer type of wattmeter, and a number of multicontact multiposition bus switches. In addition to these main elements, there are multiconductor cords with plugs and jacks as required for the interconnection between the units. No generator or load units are required, and the only circuit elements needed are enough multitap resistor assemblies to set up the maximum number of circuits connected to any one bus of the network. For example, if the actual network under study has 100 circuits, and the maximum number of circuits connected to any one bus is six, only six resistor assemblies are required to obtain a complete network setup so that readings can be taken at every bus for generation or load and for load flow in everyone of the 100 circuits.

In references 1 and 2 a new method of a-c network analysis using resistance networks is described. It was shown how the method could be applied to the conventional d-c board by making four separate resistance-network setups to simulate the a-c impedance network. It was further indicated that, by use of a new type of resistance board in which the four resistance networks can be set up simultaneously and handled the same as a single network, it is possible to read directly real and reactive power, current and voltages at all points in the network by means of special metering equipment. This type of board referred to in these previous papers may be classified as a constant-current type, because the generators and loads are setup in terms of current components.

As an outgrowth of the study to obtain direct readings of real and reactive power for the constant-current type of board, the principles fundamental to the simple calculator described in this paper were developed. It may be classified as a constant-potential type, because voltage components are used to set up the generation and loads on the system. The advantage of the constant-potential over the constant-current type is that it requires much less equipment.

On existing a-c boards the load unit settings for real and reactive power are obtained by first assuming what the voltage at each load bus will be under the desired loading condition on the network under study and then computing the resistance and reactance combination which will give the approximate load at each bus. After generation has been set up on the board in approximately correct amounts, it is possible to readjust the loads and generators until the board is brought into correct adjustment for recording the readings. The generators are provided with phase-angle and voltage adjustment, so that the desired amount of real and reactive power can be established by a series of adjustments between generators and between generators and loads. Therefore, before good speed can be attained on setting up an a-c board for load-flow studies, the operator must first learn by experience the technique of bringing the board into correct adjustment for a setup of a particular network and loading condition. After the board is adjusted correctly for one set of readings, it is usually a simple matter to readjust it for other loading conditions or network changes, if the changes in loadings and circuits are not too great.

On the new calculator, described in this paper, the constant-potential source may be either alternating or direct current as desired, but the a-c type is somewhat simpler, and therefore the description is limited to this type. Since the circuit elements are made up of resistors only, it is evident that the flow established through these elements is real power and is of no importance except that it does determine the watt rating of the resistors used in the design of the calculator. The manner in which resistance circuit elements are set up with voltage components impressed across them to obtain a simulated flow of real or reactive power through them is the basic principle of the new calculator. Although one means of measuring this simulated real and reactive power flow is described, there are other methods of accomplishing these measurements.

The simulated real and reactive power flow on the new calculator is obtained by setting up the inphase and quadrature components of voltage, which in the operator's judgment would be likely to exist at each bus in the network under study with a particular loading condition. In effect, this is similar to the technique used in setting up the generator units on an a-c board of the conventional design.

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Because the loads, as well as the generators, are set up in this way, it is evident that more adjustments will be required to bring this new calculator into correct balance for a particular loading condition on the network. Therefore, as with existing a-c boards, the speed with which results can be obtained with this new device depends on the technique of the operator in making a series of adjustments at generator and load points to bring the board into correct balance for reading. It may be granted that the new board requires a greater number of adjustments to obtain a correct balance which will consume additional time. However, this does not mean that the device will not make an excellent showing as compared to other means of analyzing load flow in a-c networks. Also, as with existing a-c boards, after a network has been set up and brought into balance for one particular loading condition, if changes are made in the network or in the loading that are not too great, it will be a simple matter to readjust this board to suit the new conditions.

There are some points in the favor of the new calculator in addition to its extreme simplicity in design, small size, and low cost. One point is that it could be handled easily by a single operator. A second point is that, because of the small number of resistances required for circuit elements, they can be of a wattage rating that will allow substantial amounts of current to flow, so that the sensitivity of the measuring instrument need not be so great. A third point is that, because of its simplicity, the network connections can be made in a minimum time. A fourth point is that, by the elimination of generator and load units, it does not necessitate the reduction of an extensive network in advance to bring it down to a certain number of generators or loads before it can be set up on the board.

The circuit theory which is fundamental to this new calculator was presented in detail in the two references and therefore only a brief summary of this theory will be given as a background for the development of the equations for real and reactive power which are basic to the design of the new constant-potential type of calculator.

Mathematical Basis for New Calculator

If a vector current $I=I_p+jI_q$ is flowing through a three-phase circuit of impedance $Z=R+jX$ ohms to neutral, the voltage drop to neutral is $V=V_p+jV_q=(I_pR-I_qX)+j(I_qR+I_pX)$ where vector V refers to the same reference axis as vector I.

If a vector voltage drop $V=V_p+jV_q$ occurs in a circuit with impedance $Z=R+jX$, then the vector current flowing will be $I=I_p+jI_q=(GV_p+BV_q)+j(GV_q-BV_p)$ where conductance $G=R/Z^2$ and susceptance $B=X/Z^2$.

If the voltage to neutral at one end of the circuit is $E=E_p+jE_q$ volts, then, with balanced loading on the three phases, at this end the real power is $P=3(E_pI_p+E_qI_q)$, and the reactive power is $Q=3(E_pI_q-E_qI_p)$.

By substitution these equations P and Q may be rewritten

$$P=3E_p(GV_p+BV_q)+3E_q(GV_q-BV_p)$$

and

$$Q=3E_p(GV_q-BV_p)-3E_q(GV_p+BV_q)$$

To put the equations in a more useful form for the calculator design, let $M=1/G$ and $N=1/B$.

$$P=3E_p(V_p/M+V_q/N)+3E_q(V_q/M-V_p/N)$$

and

$$Q=3E_p(V_q/M-V_p/N)-3E_q(V_p/M+V_q/N)$$

In case it is desired to obtain the total net real and reactive power flow in a group of circuits connected to a common bus, the equations may be rewritten as follows:

$$P=3E_p[\Sigma(V_p/M)+\Sigma(V_q/N)]+3E_q[\Sigma(V_q/M-\Sigma(V_p/N)] \quad (1)$$

$$Q=3E_p[\Sigma(V_q/M)-\Sigma(V_p/N)]-3E_q[\Sigma(V_p/M)+\Sigma(V_q/N)] \quad (2)$$

Equation 1 states mathematically that the total net real power in a group of circuits connected to a common bus is equal to the algebraic sum of the real power flow in the individual circuits which combine to make up the group. Equation 2 is similar, except that it covers the same case for reactive power. These two equations are fundamental to the design of the new calculator, and this will be shown by illustrative diagrams later in the paper.

If a generator supplies a group of circuits from a bus, the algebraic sum of the real power flowing in the circuits is a measure of the real power supplied from the generator. Likewise the algebraic sum of the reactive power in the circuits is a measure of the reactive power supplied from the generator.

If a load is supplied from a bus which in turn is supplied from a group of circuits, then the algebraic sum of the real power flowing in the circuits is a measure of the real power supplied to the load. Likewise, the algebraic sum of the reactive power in the circuits is a measure of the reactive power supplied to the load, or, in case the load has leading power factor, it will be a measure of the reactive power supplied from the load.

The convention used in this paper is that power flow in a circuit, or group of circuits, is "out" if it flows away from the bus. As indicated on a zero-center wattmeter, "out" is to the right of zero. If power flow is toward the bus, it is "in"

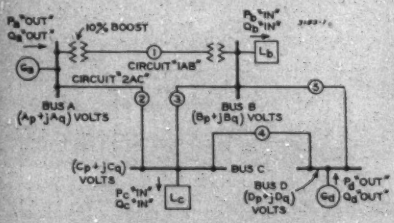

Figure 1 (left). One-line diagram of three-phase network to be used to illustrate connections and operation of calculator

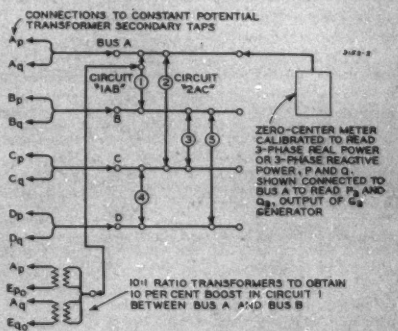

Figure 2 (right). Plugging diagram for network of Figure 1, as it would be connected on the calculator

and would be indicated to the left of zero center on the instrument scale.

Reactive power flow in an indicated direction usually carries a negative sign to make it conform to the mathematical relationship it has with the quadrature component of current. In this case, however, the negative sign may be disregarded by using the convention of "out" and "in" which corresponds to the convention previously described for real power.

Calculator Operating Technique

The best way to establish an operating technique for this new calculator is by experience with the device, but it is possible to point out several factors which will aid in determining what procedure might be used in setting up the voltage components for a test on a network.

For the (X/R) ratios usually encountered in the circuits of an electric-power system, the following generalizations may be made:

1. At generator busses, both E_p and E_q would be set at a higher positive voltage tap than at load busses, because real and reactive power flowing in the same direction in a circuit will cause a drop in E_p and E_q. The amount of the drop in the two components will depend on the amount of real and reactive power flowing and the values of X and R for the circuit.

2. At load busses close to generation, both the E_p and E_q would be set at a higher positive voltage tap than at load busses more remote electrically from generation.

3. At load busses where reactive power is supplied to the network because of a synchronous condenser or other capacitance, then the E_p component may be more positive than that at surrounding busses, even though the real power flow is toward this bus. The value of E_q will be less positive or more negative than that of the surrounding busses in this case.

Description of New Calculator as Illustrated by Figures 1 to 4, Inclusive

Figure 1 shows the one-line diagram of a simple three-phase a-c network which is used as a basis for illustrating the setup and operation of the new calculator for determining load flow. Although the network is small and is self-explanatory on the diagram, it should be noted that it covers the pertinent points of generation, loads, and one circuit with step-up and step-down transformers set at different taps so that a net boost is effective in the closed loop of which this circuit is a part.

In setting up the network of Figure 1 on the calculator, it is necessary to establish the circuit constants $M=Z^2/R$ and $N=Z^2/X$ on the common kilovolt-ampere or voltage base of the board. In the case of circuit 1AB which includes the two transformers, the lumped-impedance method is used as the basis for obtaining the values for M and N for circuit 1AB, and then a ten per cent series boost is inserted in this lumped circuit from A to B.

Figure 2 shows the schematic plugging diagram for the network of Figure 1 as it would be set up on the calculator. The movable cords, or other means of adjusting connections, are indicated by the heavy lines with the plugs and jacks shown as arrows and small circles, respectively. It should be noted that the plugging arrangement is simple and straightforward so that the connections can be made quickly.

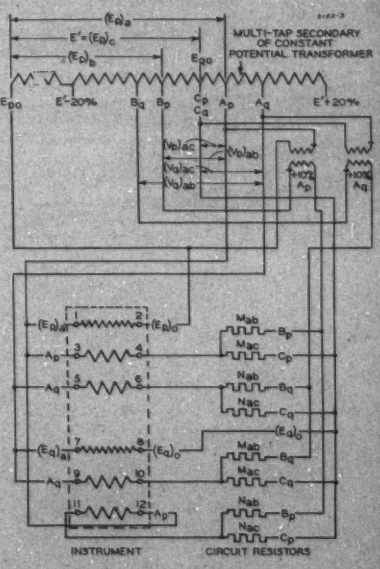

Figure 3. Schematic diagram of connections when measuring power flow at bus A of the network of Figure 1

Fundamental equation for three-phase power:
$P=3(E_pI_p+E_qI_q)$ where E_p and E_q are to neutral

Measurement of three-phase power fed to bus A by generator G_a is obtained by measuring the algebraic sum of the power flowing from bus A to bus B in circuit 1 and to bus C in circuit 2

$$P_a=3(E_p)_a\left[\frac{(V_p)_{ab}}{M_{ab}}+\frac{(V_p)_{ac}}{M_{ac}}+\frac{(V_q)_{ab}}{N_{ab}}+\frac{(V_q)_{ac}}{N_{ac}}\right]+3(E_q)_a\left[\frac{(V_q)_{ab}}{M_{ab}}+\frac{(V_q)_{ac}}{M_{ac}}-\frac{(V_p)_{ab}}{N_{ab}}-\frac{(V_p)_{ac}}{N_{ac}}\right]$$

Figure 3 shows the complete wiring for the fundamental circuit for measuring P, real power at bus A of the network. This diagram illustrates how the equation for power in terms of voltage components E_p, V_p, E_q, V_q, and circuit constants M and N may be set up with a measuring instrument to obtain a reading of real power flow. The instrument shown is essentially the same as a three-phase three-wire electrodynamometer type of wattmeter with a zero-center scale. The potential coils connected 1-2 and 7-8 are the moving coils whose combined torque act together to move the pointer. The current coils 3-4 and 5-6 are fixed coils and work together with the potential coil 1-2 to produce the torque of the upper element of the instrument. Likewise the current coils 9-10 and 11-12 are fixed coils which work together with potential coil 7-8 to produce the torque of the lower element of the instrument. The only unusual feature insofar as the instrument is concerned is that there are two fixed current coils on each of the two elements.

Referring to Figure 3, it will be seen that $(E_p)_a$, the inphase component of voltage to neutral at bus A, is acting across potential coil 1-2; that the current in coil 3-4 is the algebraic sum of $(V_p)_{ab}/M_{ab}$ and $(V_p)_{ac}/M_{ac}$; further that the current in coil 5-6 is $(V_q)_{ab}/N_{ab}+(V_q)_{ac}/N_{ac}$. The torque developed in the top element of the instrument is proportional to

$$(E_p)_a[(V_p)_{ab}/M_{ab}+(V_p)_{ac}/M_{ac}+(V_q)_{ab}/N_{ab}+(V_q)_{ac}/N_{ac}]$$

If the potentials and currents are traced for the lower element of the instrument, it will be seen that the torque developed is proportional to

$$(E_q)_a[(V_q)_{ab}/M_{ab}+(V_q)_{ac}/M_{ac}-(V_p)_{ab}/N_{ab}-(V_p)_{ac}/N_{ac}]$$

The sum of the upper- and lower-element torques is proportional to $P/3$ in the equation for power, P. The instrument

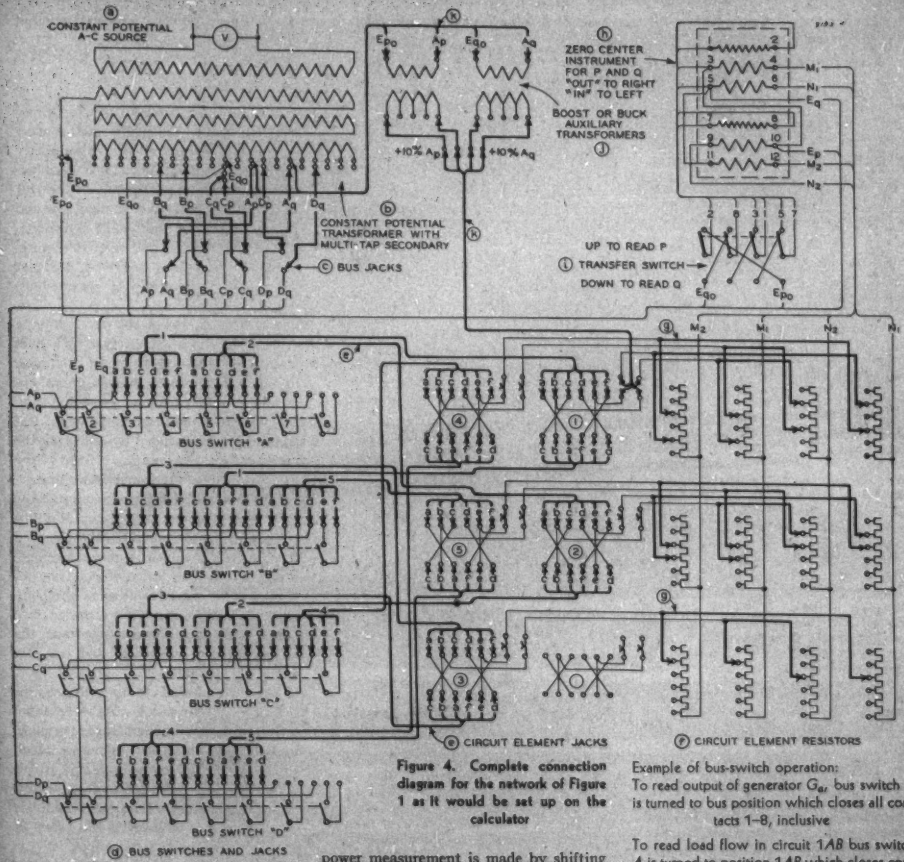
CONSTANT POTENTIAL A-C SOURCE
ZERO CENTER INSTRUMENT FOR P AND Q "OUT" TO RIGHT "IN" TO LEFT
BOOST OR BUCK AUXILIARY TRANSFORMERS
CONSTANT POTENTIAL TRANSFORMER WITH MULTI-TAP SECONDARY
BUS JACKS
UP TO READ P
TRANSFER SWITCH
DOWN TO READ Q
BUS SWITCH "A"
BUS SWITCH "B"
BUS SWITCH "C"
BUS SWITCH "D"
CIRCUIT ELEMENT JACKS
CIRCUIT ELEMENT RESISTORS
BUS SWITCHES AND JACKS

Figure 4. Complete connection diagram for the network of Figure 1 as it would be set up on the calculator

Example of bus-switch operation:

To read output of generator G_a, bus switch A is turned to bus position which closes all contacts 1–8, inclusive

To read load flow in circuit $1AB$ bus switch A is turned to position $1AB$ which closes contacts 1–4, inclusive, but opens all other contacts

To read $2AC$ bus switch A is turned to $2AC$ which closes contacts 1, 2, 5, 6 but opens all other contacts

Circled letters refer to items described in paper

— Flexible connection cord

O— Plug inserted in jack or one point of a polarized plug on a multiconductor cord

— Lightweight lines indicate fixed wiring

scale calibration may be made to read the three-phase power, P.

This reading for power is the sum of that flowing in the two circuits $1AB$ and $2AC$, and therefore it is also equal to the generator G_a output.

To obtain the power flow in the circuit $1AB$ it is only necessary to turn the bus A switch to position $1AB$ which disconnects $1AC$ circuit from the meter. Likewise, to read power flow in $1AC$, the bus A switch would be turned to $1AC$ position which disconnects $1AB$ circuit from the meter. This bus switch is not shown on Figure 3, but it is shown on the more complete diagram on Figure 4.

Because of the similarity of the reactive-power measurement to that described for real power, a separate diagram and discussion are not included. The reactive-power measurement is made by shifting E_p and E_q potential connections with respect to the currents by means of a transfer switch as shown on Figure 4.

Figure 4 is a complete wiring diagram of one arrangement for the new constant-potential resistance-circuit type of network calculator. It meets the requirements of the simple plugging arrangement of Figure 2 for the complete setup of the networks shown on Figure 1.

The calculator consists of the following elements:

(*a*). Constant-potential a-c source.

(*b*). Constant-potential transformer with multitap secondary winding.

(*c*). Plugging cords for connecting between transformers secondary tap jacks and bus jacks.

(*d*). Bus switches, multipole and multiposition.

(*e*). Plugging cords for connecting between bus-switch jacks and circuit-element jacks.

(*f*). Circuit-element resistors, multitap.

(*g*). Plugging cords between circuit-element jacks and circuit-element resistors, or the equivalent in multiposition switches.

(*h*). Zero-center measuring instrument for real and reactive power.

(*i*). Transfer switch to connect meter for real-power or reactive-power measurement.

(*j*). Boost or buck auxiliary transformers.

(*k*). Plugging cords for boost or buck transformers.

(*l*). Miscellaneous fixed wiring.

Figure 2 showed the fundamental plugging arrangement in a simple manner, and Figure 3 illustrated the basic principle of the calculator design, so that only a brief discussion is presented on some of the elements as shown on Figure 4.

(*a*). The constant-potential a-c source to the primary winding of the supply transformer should be regulated closely, and there are several static types of constant-voltage regulators on the market which would be ideal for this duty.

(*b*). The constant-potential a-c transformer with tapped secondary winding should be of ample design so that the regulation could be neglected and, by supplying a constant potential to the primary winding, the voltage at the secondary taps would remain at fixed values. The range for the taps as shown would allow for a 40 per cent difference in each of the voltage components over the network, from reference point E^1 or $(E_q)_o$ to plus 20 per cent of E^1, and from reference point to minus 20 per cent of E^1, where E^1 is the value of the reference voltage to neutral. From test computations the secondary taps may be at intervals of approximately 0.5 per cent of E^1. For simplicity on the diagram, taps are shown at intervals of two per cent of E^1.

(*c*). Plugging cords between transformer secondary taps and bus jacks could be replaced with multiposition switches if desired.

(*d*). The bus switches are shown with enough contacts to take care of three circuits per bus. These could be extended to take care of any number of circuits per bus. Probably a logical design would be to use about a six-position switch which would take care of metering the total at the bus and five individual outgoing circuits, and then, when more circuits than five are connected to a single bus, additional bus switches would be assigned to that particular bus to take care of the additional circuits. It is possible to replace the bus switches with bus jacks and cords, but the switches should give a means of speeding up the taking of readings. Another alternate to the bus switches would be the use of small relays actuated by push buttons.

(*e*). The plugging cords between bus-switch jacks and circuit-element jacks are six-conductor flexible cords, all similar. The change in the rotation of the lettering between the connections to the top and bottom jacks is taken care of by cross connection between the jacks, as shown on the diagrams, so that all of the cord plugs are polarized in the same way.

(*f*, *g*). The circuit-element resistors are multitapped, and four resistors make up a single circuit element. These resistors can be set up in pairs, because two are for the M setting, and two are for the N setting. Although cords are indicated as the means of choosing the proper resistor tap, the same results may be obtained by having a suitable number of rheostat-type multicontact switches. As discussed earlier in the paper, the number of resistor units required for the calculator is dependent on the maximum number of circuits connected to any one bus. This means that each unit may be set up to simulate any number of circuits, provided they do not connect to a common bus.

(*h*). The operation of the zero-center measuring instrument is discussed fully in connection with Figure 3. There is one feature which has not been included. It should be provided with several scales and a multicontact switch for switching from one scale to another to suit the range required for a particular measurement. Probably the multirange would be obtained by the use of multipliers in the two potential circuits.

(*i*). The transfer switch for the measuring instrument operates to transfer the potentials, so that in the up position the instrument reads real power and in the down position it reads reactive power. Because of the simplicity of the board, it might be advisable to have separate instruments for real and for reactive power, so that, when changes are made in potential connections to bring the board into balance, the effect of the changes could be observed on the two instruments at the same time and thereby the adjustment might be speeded up.

(*j*). The boost or buck auxiliary transformers are provided to take care of the effect of net boost or buck in a circuit which forms one branch of a closed loop in the network. The impedance of these should be low as compared to the resistance values used in the circuit elements, so that the transformer introduces a series boost or buck without changing the circuit constants appreciably.

(*k*) and (*l*) require no explanation other than the diagram.

Conclusions

A network calculator, of an entirely new form, and of unusually small proportions in physical size and in the simplicity of its electrical elements, has been described in this paper. It may be used for analyzing a-c networks for load-flow and voltage conditions and for the determination of system losses and reactive requirements. In the form described, it is not applicable to the study of system fault conditions.

Although not specifically covered in the discussion, it is apparent that long lines may be set up on this type of calculator by using constants based upon the nominal or equivalent π. In such a case, the effect of the leading reactive and leakage can be included by adjusting the measurement of generation or load at the two terminals of the transmission line.

In the general discussion section of the paper the technique of operating this new calculator was compared to that now used for complete a-c boards of conventional design. The new calculator is not intended to be the equivalent of the complete a-c board but instead is designed to fill the gap which now exists between the a-c analyzer or calculator and complex analytical methods.

The writer intends to build this simple calculator as soon as it is possible to do so, and, on the basis of operating experience, to determine the board technique which will give the quickest results. If it proves to be slower than the complete a-c board and yet much faster than other methods of analysis, it is believed it will prove to be a completely satisfactory tool.

References

1. Method for A-C Network Analysis Using Resistance Networks, Waldo E. Enns. AIEE Transactions, volume 61, 1942, December section, pages 875–80.

2. Apparatus for A-C Network Analysis, Waldo E. Enns. United States patent 2,323,589, July 6, 1943.

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Survivors of sea casualties are easier to spot from a rescue plane now that both the Army and Navy are providing life jackets with special packets containing a "tea-bag" of fluorescent dye. In times of emergency the dye is readily released to spread quickly over a large area of the sea. One problem in the manufacture of these packets was to find a coating and an adhesive that were strong, waterproof, and that would protect the dye at extreme temperatures. The answer was found in a VINYLITE Plastic. Cloth is coated, then instructions are printed on it. The "tea-bag" is inserted and the packet edges are heat-sealed, using the coating as the adhesive.

A manufacturer of machine roll coverings experimented with an extruded tube of VINYLITE Elastic Plastic applied over the metal core. But, with vulcanizing impossible, how could this new material be successfully bonded? The answer came in the form of an adhesive made with VINYLITE Resins. And because VINYLITE Plastics do not oxidize the new platen is proving to be superior to its rubber predecessor.

These two storage tanks contain concentrated sulfuric acid. The temperature of the metal is usually between 90 and 100 degrees F. There is considerable spillage. Under these conditions, ordinary coatings broke down in less than a month. One year ago the tanks were refinished with VINYLITE Resin VMCH air-dry coating. Today, although stained by spilled acid, this coating is unharmed.

Tiny grommets must be made by the thousands to supply the needs of American military planes and trucks. Today these grommets are injection molded of a VINYLITE Elastic Plastic. This conversion saves large quantities of critical rubber, but even more important, it cuts molding time to a fraction of that formerly needed. Scrap and trim can be remolded immediately without costly re-processing.

Important blueprints became oil stained, wrinkled, and torn in war-plant shops. How could they be made more durable to eliminate this waste? Now a thin sheet of VINYLITE Elastic Film, backed with paper, is laid over the print . . . then ironed on at moderate temperature. The thermoplastic film softens . . . adheres to the print. As soon as it cools the backing paper is stripped off, leaving a strong, glossy, water- and oil-proof coating.

Bomber floor mats and catwalk mats must be skidproof and unaffected by oil. A prominent rubber company, using standard rubber-processing equipment, calendered VINYLITE Elastic Plastics on a cloth base . . . embossed the surface for maximum traction. Since VINYLITE Elastic Plastic requires no curing or vulcanizing these sturdy, skidproof, oilproof mats are made at low cost.

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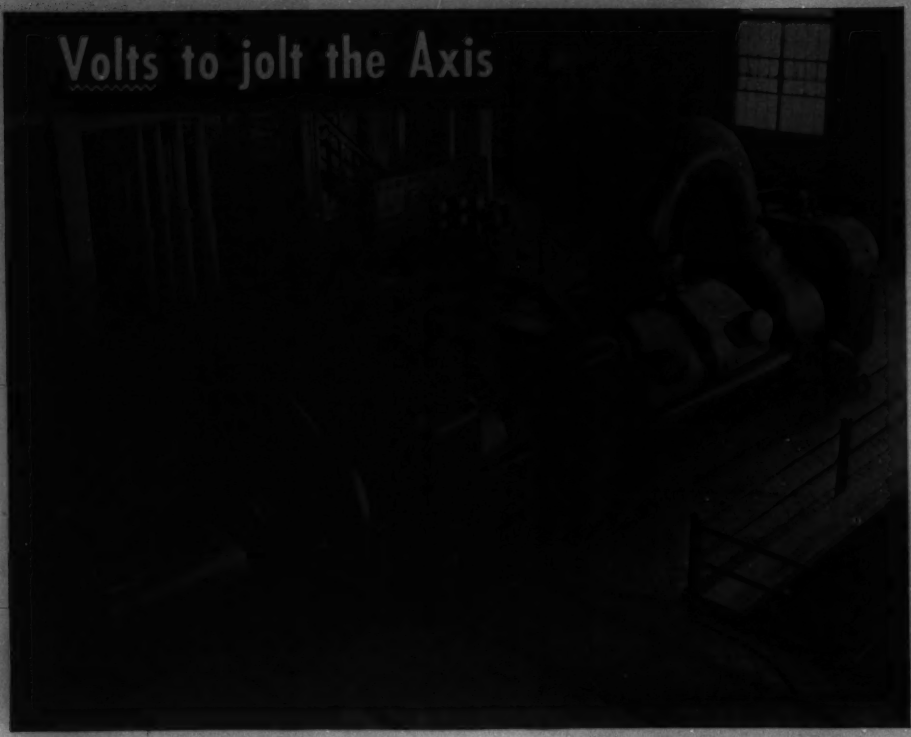

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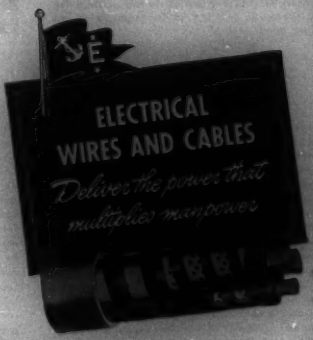

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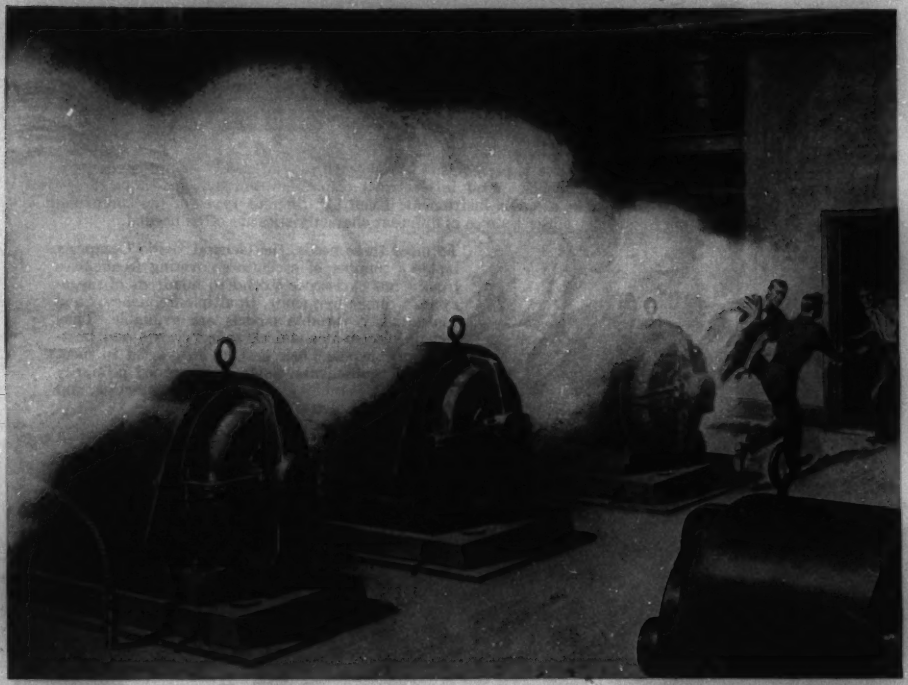

Why the engineer was only partly right

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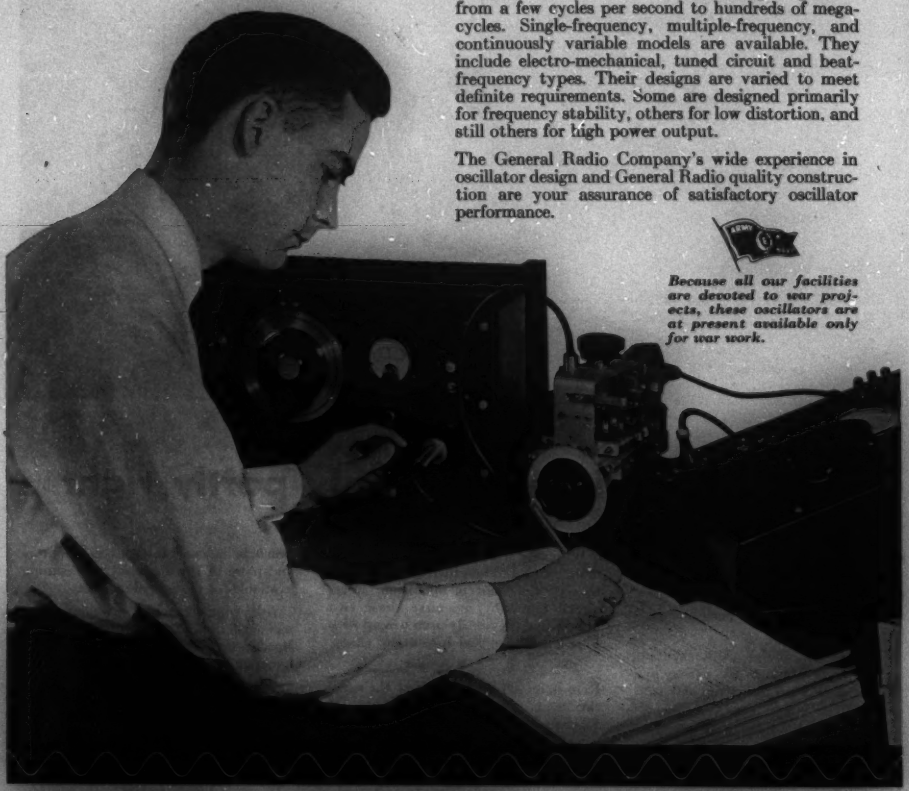

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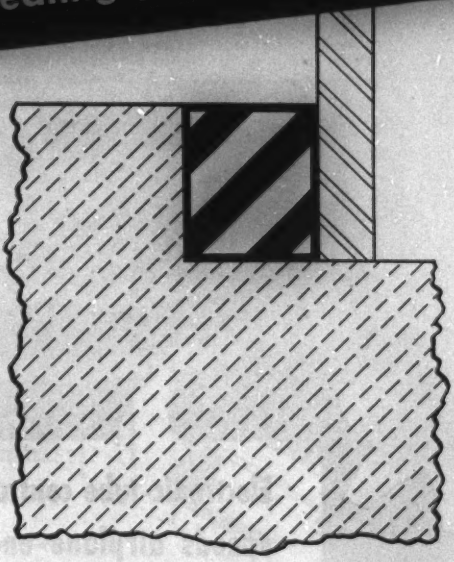

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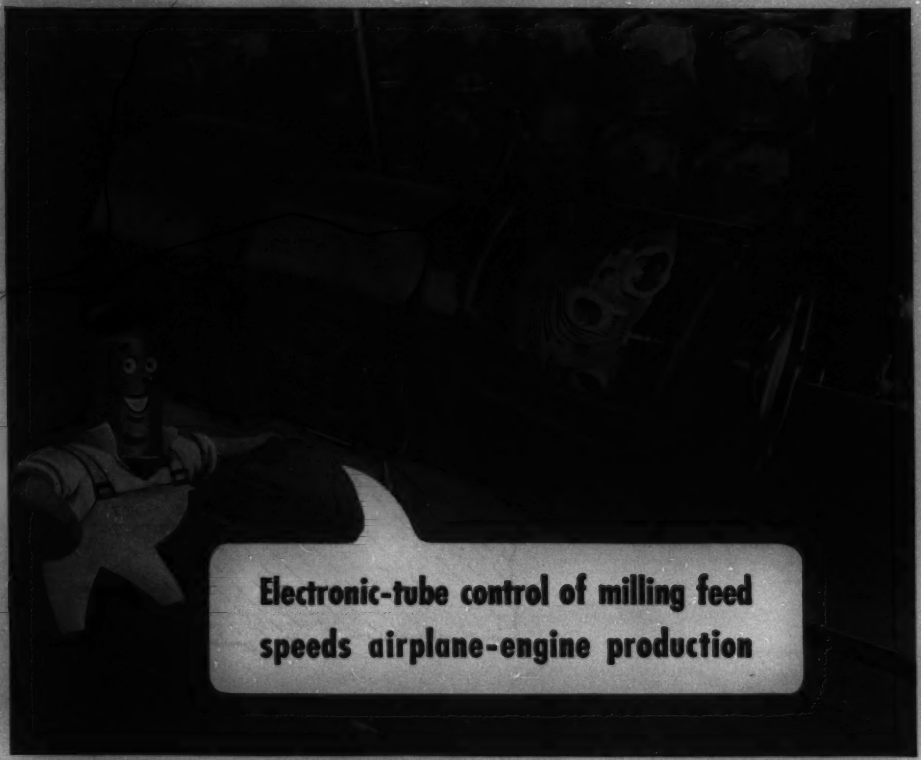

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The General Electric Thy-mo-trol is standard equipment on the Plan-O-Mill. Thy-mo-trol is an electronic motor control unit that gives separate control of feed-in and feed-around.

It is a General Electric electronic tube, the thyratron, which makes possible the operation of Thy-mo-trol. The thyratron acts as a lightning-fast automatic switch, responding to and correcting load variations so that cutter speed stays constant. It is also a rectifier, converting alternating current into direct current.

Change of gears and sheaves are unnecessary in this motor control operation. Feed changes are automatic, and cutter speed remains constant regardless of variations in load. If the load limit is exceeded, motor control shuts the power off, protecting the feed mechanism.

It is the purpose of the G-E electronic tube engineers to aid any *manufacturer* of electronic devices in the application of tubes. Through nation-wide distribution, G.E. is also prepared to supply *users* of electronic devices with replacement tubes.

FREE BOOKLET ON ELECTRONIC TUBES

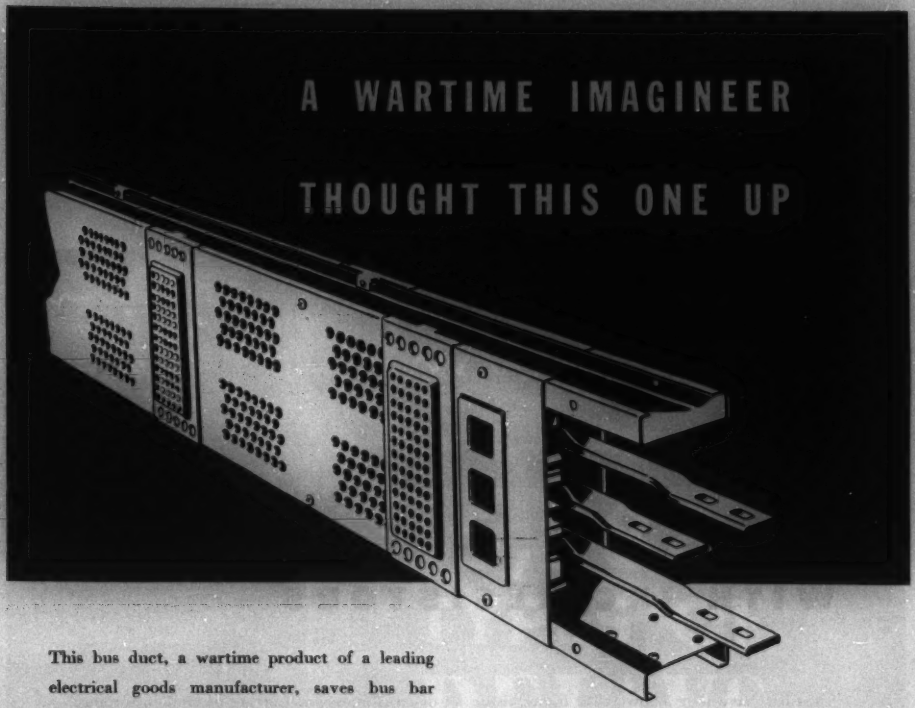
We would like to mail you, without charge, an illustrated book entitled "How Electronic Tubes Work," written in easy and understandable language, and showing typical electronic tubes and their applications. Address *Electronics Department, General Electric, Schenectady, N. Y.*

• *Tune in "THE WORLD TODAY" and hear the news direct from the men who see it happen, every evening except Sunday at 6:45 E.W.T. over CBS. On Sunday listen to the G-E "All Girl Orchestra" at 10 P.M. E.W.T. over NBC.*

THERE IS A G-E ELECTRONIC TUBE FOR EVERY PURPOSE

GENERAL ELECTRIC

A WARTIME IMAGINEER THOUGHT THIS ONE UP



This bus duct, a wartime product of a leading electrical goods manufacturer, saves bus bar material by permitting heat to be dissipated faster; smaller bus cross sections can be employed for equal ratings. And it saves on the housing material by using perforated metal instead of solid sheet.

This is an excellent example of what we mean by *Imagineering*. Some engineer departed from standard channels of thinking, and produced a "substitute" which may have its effect on future construction.

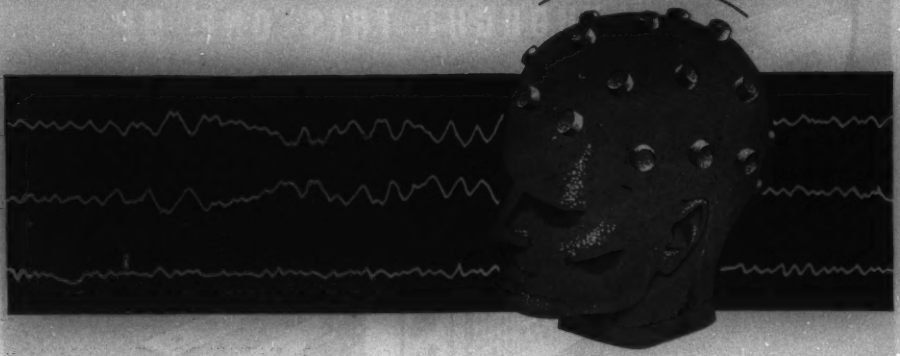
Now, when postwar designers say, "Make both the bus bar and the housing of Alcoa Aluminum," that will be plain, good *Engineering*. The weight savings effected by building with aluminum means less burden to be carried by supports. Aluminum bus bars have ample current-carrying capacity and aluminum housings provide additional electrical advantages.

Prewar power lines of A.C.S.R., Alcoa Aluminum bus bars and housings, are serving thousands of war industries—visible evidence that it pays to Imagineer with aluminum. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Bldg., Pittsburgh, Penna.

IMAGINEERING AT WORK

ALCOA A·C·S·R

TUNING IN ON *Brain Tissue*



WITH IRC RESISTORS

Scientists have long known that living tissue generates minute electric potentials. But only recently have researchists been able to adapt this knowledge to clinical use on the human brain through means of the Electroencephalograph.

In its functioning, tiny electrodes are fastened to the skin by collodion at the points indicated in the illustration. The average potentials of only 50 microvolts are led to a high-gain amplifier and enlarged to a size where the waves are easily visualized. Comparative studies of the graphs obtained from various brain areas indicate and localize the presence of abnormalities, if any exist.

Quite naturally for such a sensitively adjusted instrument, measuring minute voltages, details of resistor construction are of vital importance in addition to the inherent stability, precision, low noise level and other characteristics which

ANOTHER IRC DEVELOPMENT

are fundamental requirements. IRC is proud to have collaborated in the evolution of the Electroencephalograph and to have had its resistors and specialized engineering skill play a part in its development.

If you are seeking unbiased counsel on a resistance problem, consult IRC—the company that makes resistor units of more types, in more shapes, for more applications than any other manufacturer in the world.

PREFERRED FOR PERFORMANCE • IRC • FIXED & VARIABLE RESISTORS

ARMY E NAVY

INTERNATIONAL RESISTANCE COMPANY

427 N. Broad Street • Philadelphia 8, Pa.

STRUTHERS-DUNN

INCORPORATED

5,288
TYPES OF
RELAYS

1321 ARCH STREET, PHILADELPHIA 7, PA.

NO QUESTIONABLE PORCELAIN CAN SURVIVE THIS TEST

Lapp suspension insulator units, before being approved for shipment, must withstand the Overpotential Test, the industry's most severe test of porcelain quality. Its rim immersed in oil to prevent flashover, the unit is subjected to 60 cycle current at voltage higher than rated flashover value. Porcelain not up to the Lapp standard, punctures in this test, never gets a chance to fail on your lines. Units that survive are assured a definite dialectric factor of safety. The Overpotential Test is one of the many reasons that you do better with Lapp insulators on your lines. May we tell you the whole story? Lapp Insulator Co., Inc., LeRoy, N. Y.

ARMY E NAVY

Lapp

Better Porcelain • Better Insulators

Federal Battery Chargers and Power Supplies

for all Communications Needs...

. . . powered by I. T. & T. Selenium Rectifiers

Typical Automatic Noiseless Telephone Battery Charger

Built for highest efficiency and powered by long-life I. T. & T. Selenium Rectifiers, Federal Battery Chargers and Power Supplies are available in all types and sizes, in a wide range of ratings, to meet every communications requirement — telephone, telegraph, signaling and alarm systems. The many types include automatic regulated noiseless chargers and battery eliminators, manually operated units and non-filtered types.

Federal Battery Chargers and Power Supplies provide important operating advantages: no routine maintenance; no radio interference; hum-free output; high overall efficiency. They are for use on commercial AC circuits; they are rugged and compact and have a minimum of critical materials.

The "power unit"—the I.T.&T. Selenium Rectifier introduced and manufactured by Federal — is standard in the electrical field. Its freedom from moving parts, its wide temperature operating range, its capacity for overload and unlimited life, assure stable and satisfactory performance. *Consulting engineering services available from Technical Department.*

Federal Telephone and Radio Corporation

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An IT&T Associate

1000 Passaic Ave, East Newark, New Jersey

PERMANENT MAGNETS MAY DO IT BETTER

DESIGN

CONTROL

PRECISION

33 YEARS OF "KNOW-HOW"

. . . available to you!

WHILE age alone provides no claim for preferential consideration, our 33 years in this industry have given us exceptional experience in permanent magnet applications. This experience should prove invaluable to you in the solving of your engineering and development problems.

Permanent magnets are now being utilized in many applications not previously apparent. Units of our design and manufacture have increased the uses and improved the functions of countless products. Among those important to the war effort are some of this country's most vital electronic devices.

Our engineers will be pleased to consult with you and give your problems the benefit of their knowledge.

Write on your letterhead, for the address of our office nearest you—and our 30-page "Permanent Magnet Manual".

BUY AN EXTRA WAR BOND!

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Company

★ SPECIALISTS IN PERMANENT MAGNETS SINCE 1910 ★

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DOLPH'S INSULATING VARNISHES

Today, the largest American Merchant Marine is getting the supplies through to the Allied Armies. Their safety and reliability in delivering the goods depends upon the sychronous functioning of electrical and mechanical equipment.

A mere film of DOLPH'S Insulating Varnish is playing an important part by protecting the electrical equipment against salt water, oil and corrosive chemicals, insuring dependable performance.

Your electrical units, too, may be given the same protection. Why not write today and learn how DOLPH'S Insulating Varnishes can do a better job for you. They are formulated to meet the most rigid specifications.

JOHN C. DOLPH CO. INSULATING VARNISHES

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PRESENT power systems

PLUS G-E carrier current

SAFELY deliver more kilowatt hours

MANY power companies—faced with increased power demands for war uses—can deliver more kilowatt hours and stay well within safe operating limits by installing modern G-E carrier-current equipment. Regardless of the type of carrier function needed, General Electric can supply it.

Besides offering all types of carrier-current equipment, an exclusive feature of G-E design is its package-type unit construction. For example, your immediate need may be pilot relaying to improve stability of transmission lines, increase their load-carrying capacity, and reduce outages in protected or unprotected sections. Later, when more functions are wanted, additional G-E apparatus is designed to fit quickly and easily into your original installation.

Literally "packaged" G-E carrier-current equipment can be added as needed for every purpose, if you insist on modern G-E equipment from the start.

Here are some major carrier-current functions that may boost the kilowatt-hour output of your system:

1. Pilot relaying
2. Transferred tripping
3. Automatic tie-line load control
4. Telemetering
5. Telephony
6. Supervisory control
7. Line sectionalizing control

G.E. has led the field in carrier-current design, research and application for 20 years, and its installations cover the nation. Your G-E representative will gladly discuss with you the application of carrier current to your system. . . . *Electronics Department, General Electric, Schenectady, N. Y.*

Tune in "THE WORLD TODAY" and hear the news direct from the men who see it happen, every evening except Sunday at 6:45 E.W.T. over CBS. . . . On Sunday listen to "The Hour of Charm" at 10 P. M. E.W.T. over NBC.

Transmitter-receiver assembly mounted on same column that supports the coupling capacitor; base also includes line tuning equipment and a potential device.

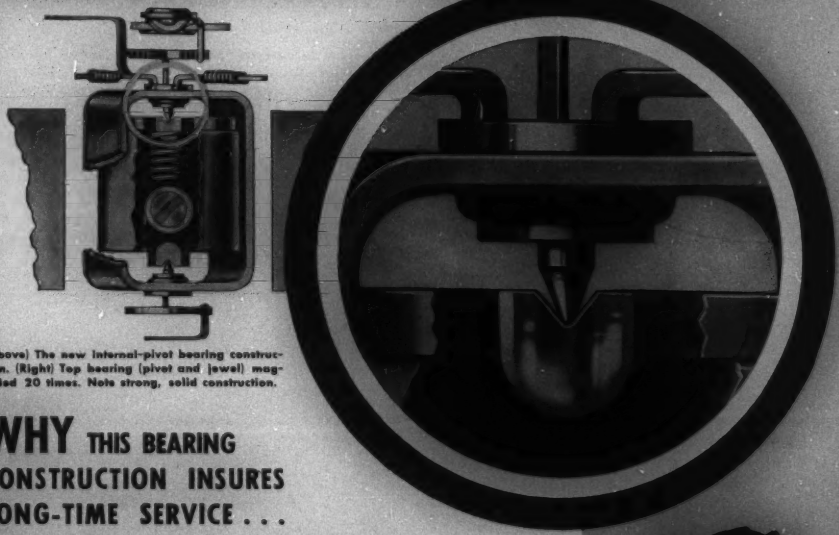
GENERAL ELECTRIC

191-94

New INTERNAL-PIVOT ELECTRIC INSTRUMENTS

2½-inch - - - 1 inch deep

For radio and other communications service; d-c voltmeters, ammeters, milliammeters, microammeters, and radio-frequency ammeters and milliammeters (a-c thermocouple type). Cases are brass or molded Textolite.



(Above) The new internal-pivot bearing construction. (Right) Top bearing (pivot and jewel) magnified 20 times. Note strong, solid construction.

WHY THIS BEARING CONSTRUCTION INSURES LONG-TIME SERVICE . . .

IN THESE new G-E instruments, the pivots are solidly mounted on the *inside* of the armature shell instead of being cemented to the outside of the armature winding. The result is a rigid construction that helps to maintain accurate alignment.

The steel pivots, highly polished, are of the aircraft type, larger than normal. This means less stress on the bearing surfaces and a construction that will stand rough treatment and shock.

The pivots rotate in low-friction, highly polished, glass vee jewels—one mounted rigidly in the top of the frame-and-core assembly, and the other mounted in a movable lower jewel sleeve located in the soft-iron core.

This combination—accurately formed, hard-glass jewels and large-radius steel pivots—provides a co-ordinated bearing that has proved, by field tests, to be excellent from the standpoint of long life and ability to withstand vibration.

Thin, Strong, Accurate Instruments

1. *Thinness* is obtained by solidly mounting the pivots on the inside of the armature shell. Most instruments are approximately one inch deep.
2. *Strength* is obtained by short, solidly mounted, large-radius pivots and the extra-strong over-all case.
3. *Sustained Accuracy* is insured by the featherweight moving element, combined with high torque and permanent alignment of all parts.

For ratings, prices, and dimensions, ask our nearest office for Bulletin GEA-4064, which covers instruments for use in radio and communications equipment; or Bulletin GEA-4117, which describes those suitable for naval aircraft. *General Electric Co., Schenectady, N. Y.*

D-c voltmeters, volt-ammeters and ammeters are specially designed to measure voltage and current in battery and battery-charging circuits on naval aircraft. They meet applicable Navy specifications.

SMALL PANEL INSTRUMENTS

GENERAL ELECTRIC

GEA-4064A

Announcing

A NEW Dielectric Material for Capacitors--

LECTROFILM—a new product developed by the General Electric Laboratories—is a synthetic dielectric made from raw materials that are available in large quantities in the United States.

Capacitor manufacturers will find it ideal for use in most radio-frequency-blocking and by-pass, fixed capacitors that for years have been built with mica. These capacitors are of the type used in communications and other electronic equipment.

Lectrofilm has a greater combination of desirable mechanical and electrical properties than any other one capacitor dielectric material. It is available in both rolls and sheets, and can be used in present capacitor production lines, little or no change being required in equipm or manufacturing methods. Its strength flexibility make it well suited to handling automatic means.

Best of all, lectrofilm has uniform charac istics; it requires little if any grading, sort or inspection. Therefore, it is economica well as easy to use, and when properly appl will cut down the number of finished capaci that are rejected in test. Users of lectro can expect increased capacitor produc with present facilities without any increas man-hours.

Lectrofilm is available for use by manufactu making capacitors for the armed forces.

LECTROFILM

TYPICAL CHARACTERISTICS

	Lectrofilm in Rolls, No. 2681	Lectrofilm in Sheets, No. 2682
D-c breakdown strength	1900 volts per mil (Two or more thicknesses)	2500 volts per mil
Dielectric constant	4.0 or more	5.5 or more
Tensile strength	Equal to Kraft capacitor paper	Equal to Kraft capacitor paper
Power factor at 1,000,000 cycles* Per cent at 25 C Per cent at 100 C	3.5 or less 1.75 or less	2 or less 1 or less
Capacitance temperature coefficient, per cent per degree C*	0.05 to 0.15	0.05 to 0.15
Maximum recommended operating temperature	100 C	125 C

*These characteristics, determined by actual test results on capacitors built with lectrofilm, will depend on the type of capacitor construction.

For information on

- sizes
- thicknesses
- weights
- additional characteristics

...write for Bulletin GEP-217A. Address: Section 16-216, General Electric Company, Pittsfield, Mass.

Every week 192,000 G-E employees purchase more than a million dollars' worth of War Bonds

GENERAL ELECTRIC

These are the BENEFITS of a CLOSELY HELD VOLTAGE SUPPLY

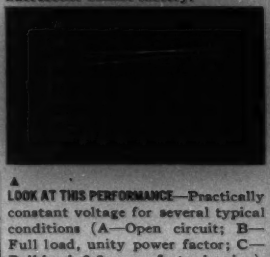
Better performance, greater reliability, and longer life of electronic devices

Protection of delicate instruments and machines, precision tools, and electronic tubes against sudden overvoltages

More accurate test results, fewer rejects

And manufacturers—don't forget:
A product's salability can be increased when voltage stabilization is a built-in feature.

EXTREMELY CLOSE VOLTAGE REGULATION, so essential to speedy, accurate production-line testing, is automatically maintained by a 500-volt-ampere G-E stabilizer on a test bench in a fluorescent-ballast factory.



...and Here's the Way to Get It

LOOK AT THIS PERFORMANCE—Practically constant voltage for several typical conditions (A—Open circuit; B—Full load, unity power factor; C—Full load, 0.8 power factor lagging). Stabilizing action practically instantaneous, taking place in less than three cycles.

IMPROVES THE PERFORMANCE OF EQUIPMENT LIKE THIS:

Radio transmitters and testing equipment
Photoelectric equipment and other electronic-tube apparatus
Motion-picture projectors and sound equipment
Telephone apparatus
X-ray machines
Precision photographic equipment and photometers
Color comparators
Calibration of meters, instruments, relays
Laboratory precision processes and testing equipment

FOR DETAILS on this stabilizer's unique circuit, write for Bulletin GEA-3634. *General Electric Company, Schenectady, N. Y.*

VOLTAGE STABILIZERS

GENERAL ELECTRIC

660-55-5095

The best investment in the world is in this country's future—BUY WAR BONDS

Seeing ...BY EAR

A fighting man must fly blind sometimes, but deaf never. In long range bombers . . . in scrappy pursuit planes . . . whatever the visibility, vital communication channels must be kept clear. Unless the proper suppression filter system is installed, noisy radio interference acts like a pack of demons . . . sabotages communications upon which the safety of men and their military missions depend.

Solar Elim-O-Stats are Communications' Life-savers. They are compact filters which protect against local static, absorbing it *right where it starts*—at generators, motors, contacts, and other sources. Solar Capacitors are reliable components used by practically all leading manufacturers of military radio equipment. From command car to jeep or tank . . . from ship to ship or plane . . . between planes—wherever radio is vital—Solar Capacitors and Elim-O-Stats help keep channels clear, so fighting men can hear.

If you have a problem concerning capacitors or radio noise suppression, call on Solar Manufacturing Corporation, 285 Madison Ave., New York 17, N. Y.

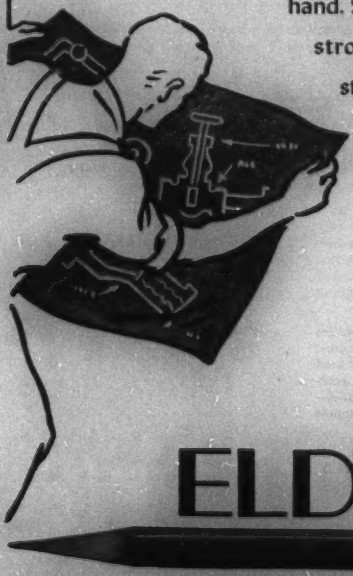
Solar SOLAR — ELIM-O-STATS

CAPACITORS AND RADIO NOISE SUPPRESSION FILTERS

TAKING THE BUGS OUT OF WORKING DRAWINGS...

How to make working drawings in a hurry—that are accurate, complete and fool-proof—is the problem.

You can devote your whole time to this problem when you have *Typhonite* Eldorado pencils in your hand. Smooth, accurately graded, strong, they do not throw obstacles in the way. You'll learn why by reading the interesting 23-page booklet describing the Typhonite process.



Write for your free copy to: Pencil Sales Department, 42-J12 Joseph Dixon Crucible Company, Jersey City 3, N. J.

TYPHONITE

ELDORADO

REMEMBER YOUR FIRST DESIGN JOB?

Chances are you do and will never forget that first contribution you made to a new and growing industry. That's the way we feel about our "first job", too—Varnished Cambric and Tape.

Shortly after the turn of the century, Varnished Fabrics became a vital factor in controlling the current that was harnessing electric power to the wheels of industry. For it was then that the Irvington Varnish & Insulator Company, a pioneer in the field of electrical insulation, began its career by developing an improved yellow varnished cambric and perfecting the manufacture of black varnished cambric. Later, as the need became evident, Irvington also developed and first introduced seamless bias cut tape.

Today, with a line embracing a wide range of electrical insulation requirements, we still regard Varnished Cambric and Tape as our "first job" and steadfastly maintain the standards which earned their early success. From its founding 38 years ago, on an unswerving policy of high quality and rigidly controlled production methods, the name "Irvington" still signifies outstanding electrical insulation.

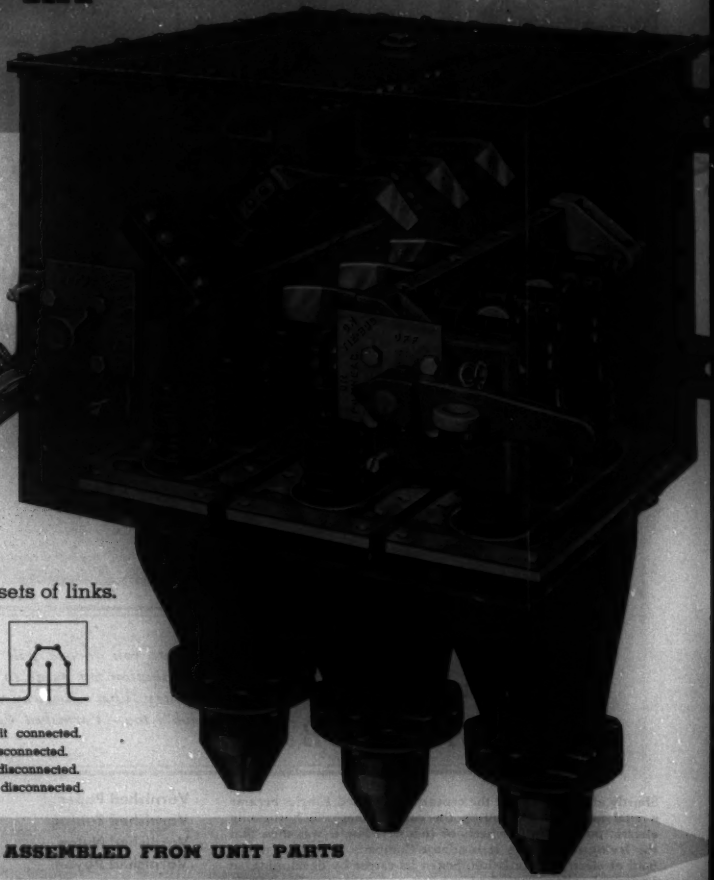
If you do not already use the dependable products manufactured by Irvington, send for latest literature on any of those listed at the right. Or, if specific information is needed on any unusual problems, our engineers are always ready to assist you. Write Dept. 36.

Varnished Paper
Varnished Tubing
Varnished Nylon
Varnished Rayon
Varnished Canvas & Duck
Varnished Fiberglas
Insulating Varnishes
Extruded Plastic Tubing
Varnished Slot Insulation

IRVINGTON VARNISH & INSULATOR CO.
Irvington, New Jersey, U. S. A.
Plants at Irvington, New Jersey, and Hamilton, Ontario, Canada
Representatives in 20 Principal Cities

IRVINGTON *Electrical* INSULATION

Quickly isolate underground cable circuits with G & W Type "RA" Subway Oil Disconnects



Simple and safe sectionalization by merely operating external lever arms.

No covers to remove.

No seals to be broken.

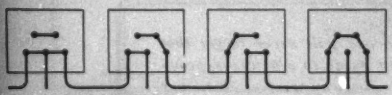
No links to unbolt.

Full 400 ampere load break with 7500 volt units—Up to 100 ampere load break with 15000 volt units—No load break with 23 Kv. and 34.5 Kv. units.

Oil filled tanks keep size to minimum—operating shafts perfectly sealed.

G & W TYPE "RAL" →

4 different connections with 2 sets of links.



1. Loop or feed through with branch circuit connected.
2. Feed branch from left with other feed disconnected.
3. Feed branch from right with other feed disconnected.
4. Loop or feed through with branch circuit disconnected.

ASSEMBLED FROM UNIT PARTS

UNIT CABLEHEAD

Tanks are welded in proper size and form and fitted with one, two or more rocker arm link units. Cableheads in straight or elbow shapes are attached to the bottom or to the bottom and sides of the tank to complete the assembly.

ROCKER ARM LINKS

WELDED STEEL TANK

G & W ELECTRIC SPECIALTY CO.

7780 DANTE AVENUE — CHICAGO, ILLINOIS

Also made in Canada by POWERLITE DEVICES, LTD., Toronto

WHEN EACH SMALL PART, as it comes from the machine—each finished article, as it comes from the assembly line—*varies not at all* from the others, the problems of QUALITY production have been solved, and QUANTITY production presents small difficulty.

Modern electrically operated manufacturing equipment is expertly designed to produce with *absolute exactness*. That's the miracle behind today's output. *But*, the mechanical perfection of each individual unit must be matched by an unfailing, unvarying power supply. Every unit, however small, must be responsible for its own security. That is why SOLA Constant Voltage Transformers are widely used to provide protection against damaging voltage variation.

Where this control is lacking, electrically operated or controlled equipment is highly vulnerable to voltage fluctuations. Devices designed to operate at rated voltages *react differently* to drops or increases in voltage. Then uniform accuracy and synchronization of the production line no longer exists. Precision work becomes impossible. Rejects increase in number.

SOLA "CVs" protect equipment and instruments, absorbing voltage sags and surges up to 30% and deliver an unchanging, specific voltage regardless of input variations from over-loaded supply lines.

Automatic and instantaneous in action, SOLA "CVs" allow no jolts or sags to slip through. They are made with the same modern exactitude as the most intricate equipment. Immediately available in standard units, capacities from 10 VA to 15 KVA, SOLA Constant Voltage Transformers can also be built to your specification.

Note to Industrial Executives: *Where there is a problem involving voltage control, no matter what its nature, SOLA "CV" Transformers can help solve it. Ask for bulletin ACV-74.*

SOLA
Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago, Ill.**

.. is making *electronic* BLOCK-BUSTERS

A design problem holding up some war project in electronics is no less important than a strategic enemy stronghold which must be blasted out of action. Immediate and skillful handling is essential.

Seemingly insuperable difficulties, such as climate, weight, shock, vibration, moisture, etc., assume an almost routine status at N-Y-T. Unusual frequency characteristics, critical limits on distributed capacity, immunity to surges, special shielding and regulation requirements find speedy solutions under constant testing, devising and experimentation.

Electronic "block-busters" will be needed in the post-war period, too. The N-Y-T Sample Department will be available for such assignments.

NEW YORK TRANSFORMER COMPANY

NYT

34-28 WAVERLY PLACE NEW YORK, N. Y.

WANTED

IDEAS, INVENTIONS or PATENTS

A company with a nationally known product would like to consider ideas and inventions suitable for post-war use in the industrial and commercial field of applying and dispensing lubricants, such as pumps, point to point, centralized lubrication, etc. Also hydraulic, vacuum, or pneumatic actuated mechanisms, pistons, valves, etc., as used in the Aircraft and Automotive field. Also passenger and industrial elevators, automatic leveling devices, controls, etc., and similar items such as portable lifting and stacking trucks or mechanisms used about factories, etc.

* * *

Before sending us any information, please write for detailed instructions, Dept. NP18, L. W. Ramsey Advertising Agency, Davenport, Iowa.

THE 2 IN 1 CABLE STRIPPER

The only tool that will both *ring* and *strip* heavy electric cable. Will handle cable up to 1½" —larger size handles cable up to 2½".

TWO TOOLS IN ONE
Economical and Efficient.

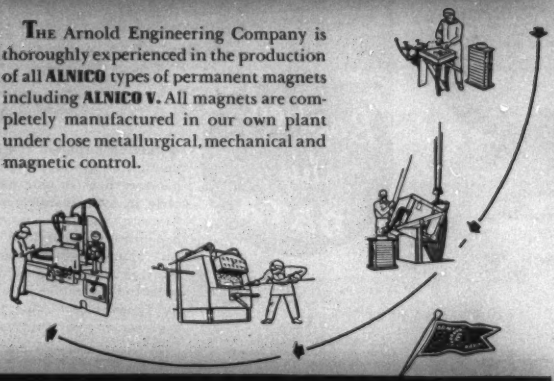
Write for prices etc.

LOYD THOMPSON

1400 Riverside Drive, Chino, California

PERMANENT MAGNETS

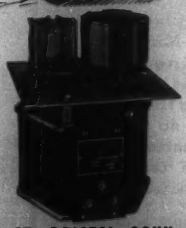
THE Arnold Engineering Company is thoroughly experienced in the production of all **ALNICO** types of permanent magnets including **ALNICO V.** All magnets are completely manufactured in our own plant under close metallurgical, mechanical and magnetic control.



THE ARNOLD ENGINEERING COMPANY
147 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS

DO YOU HAVE TO "FISH" FOR CORRECT VOLTAGE?

Your equipment can be operated at exactly the right voltage. POWERSTAT Variable Transformer control of voltage to precise limits can be made either manually or automatically. No longer is it necessary to operate electronic apparatus, heating and testing equipment and other devices at the off nominal voltages that exist on today's heavily loaded lines. Standard POWERSTATS in sizes up to 75 KVA for single or polyphase operation on 115, 230 or 440 volt circuits are designed to replace coarse tap-changing transformers and rheostats having poor regulation and limited range.

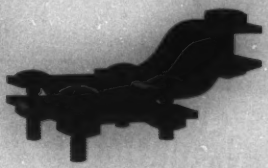


Specify POWERSTAT Variable Transformers, manufactured by SUPERIOR ELECTRIC COMPANY, the voltage control specialists.

SEND FOR BULLETINS 149 EE and 163 EE

SUPERIOR ELECTRIC COMPANY, 75 LAUREL ST., BRISTOL, CONN.

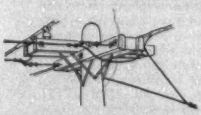
SUPERIOR *Electric Company*



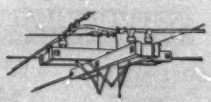
SAVE $5.00 A TURN OR DEADEND

on 000 to 1,500,000 C.M. cable with

Matthews Cable Clamps



Shows how strain caused by right angle taps can be relieved



Outside Turns, Straight Guys

Deadending Two Cables

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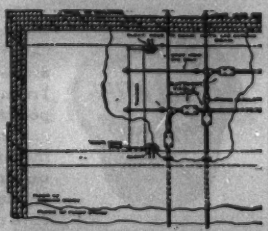

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Formed in 2 PLANES to .001" ACCURACY with

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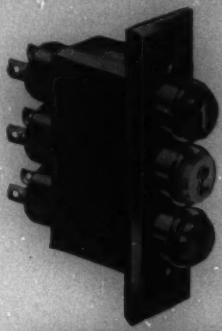

This unit is obtainable in larger size banks, in multiples of 3 pilot lights. Features include: Color-coded *flat lenses with etched numbers, letters, or words.* (Half-round lenses, in clear or sand-blasted finishes, may also be used.) Bulbs are *removable from front of panel.* Silver plated terminals are firmly secured for perfect contact. Many other Dialco features.

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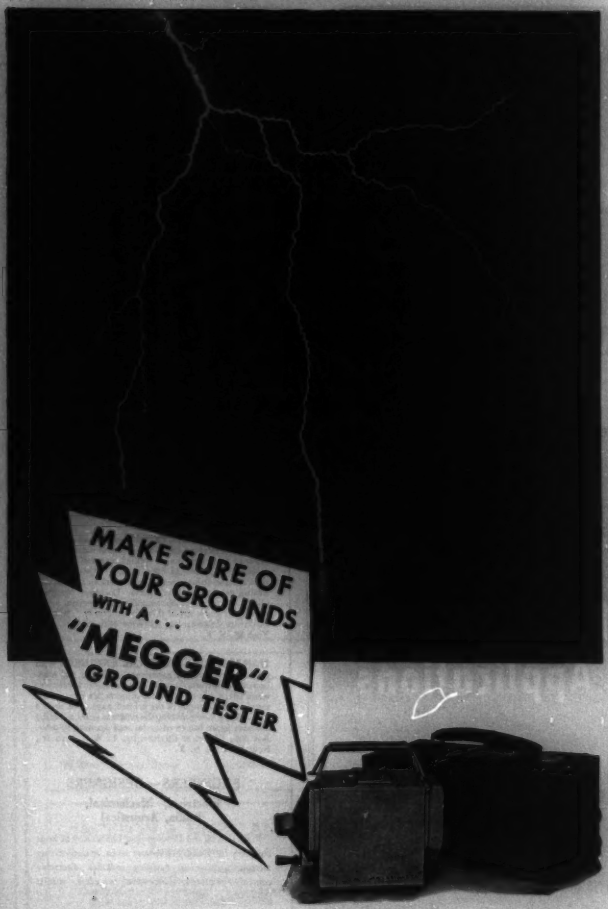

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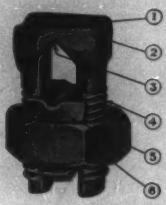

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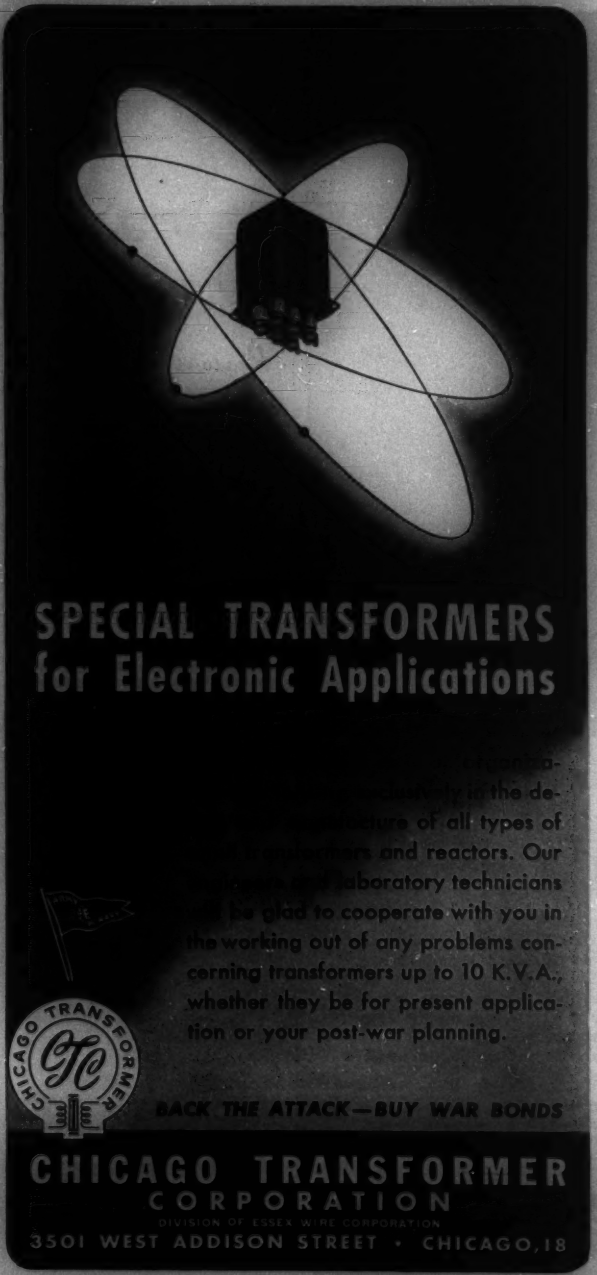
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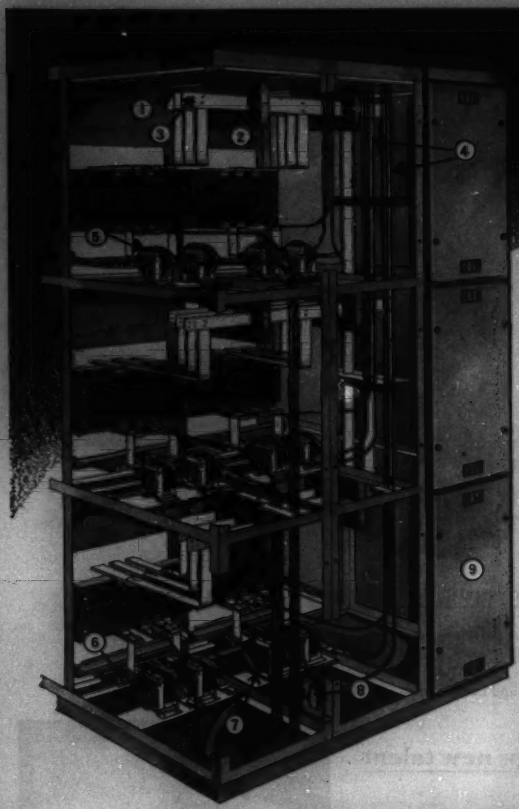

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